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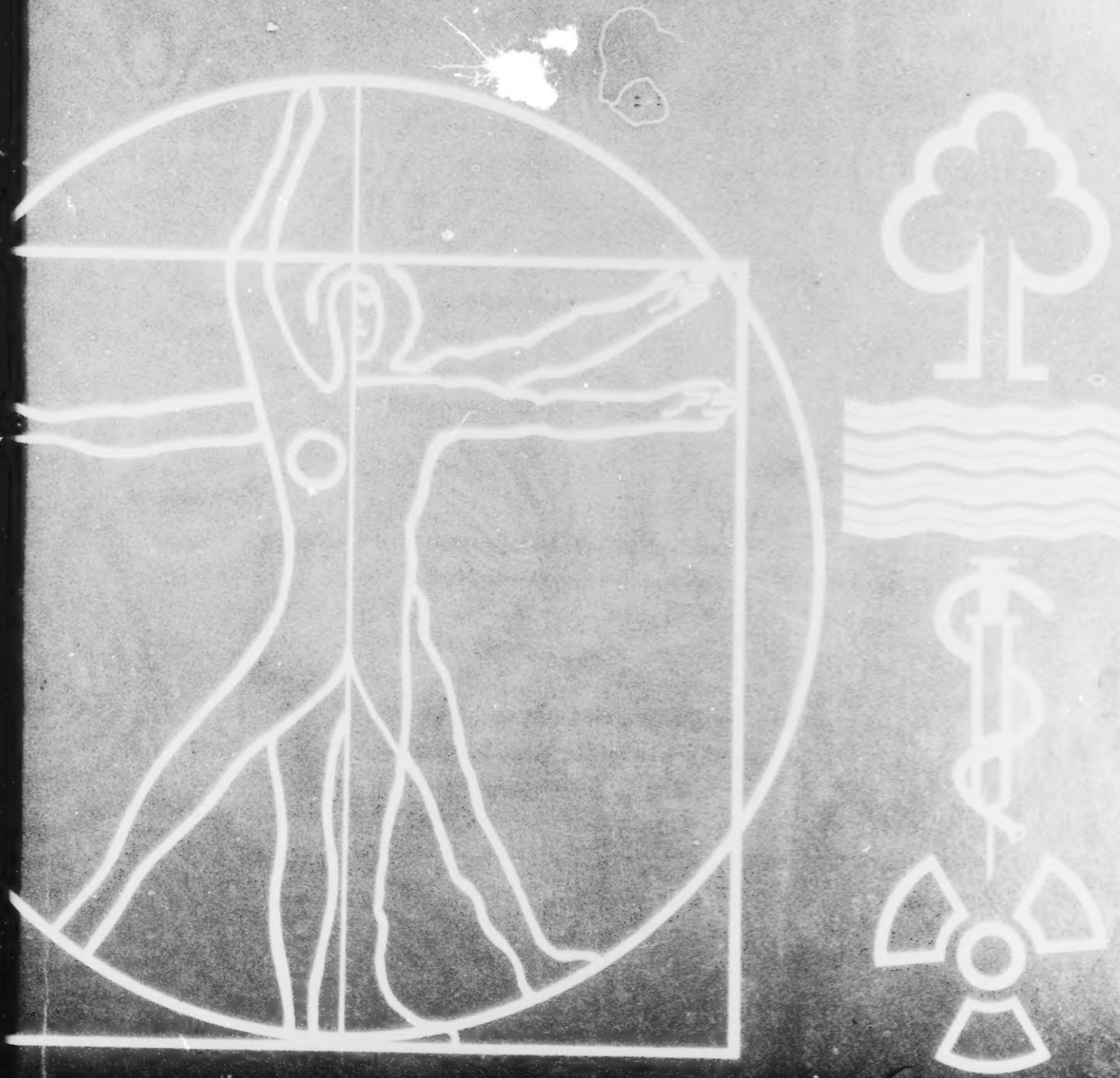
municipal wastewater disinfection in canada - need and application



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MUNICIPAL WASTEWATER DISINFECTION IN CANADA
NEED AND APPLICATION

A Report of the Working Group on
Wastewater Disinfection
to the
Federal-Provincial Advisory Committee on
Environmental and Occupational Health

Environmental Health Directorate
Health Protection Branch

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EXECUTIVE SUMMARY

BACKGROUND

The controversy over the practice of wastewater disinfection is rooted in two basic and complementary principles: the protection of human health and the maintenance of a natural, healthy environment.

Municipal wastewater treatment plant discharges often constitute a significant input source of pathogenic micro-organisms to the receiving environment. Such discharges represent a potential menace to water supplies, to recreational and agricultural uses of receiving waters and lands and to various other water related activities. Inactivation or destruction of pathogenic micro-organisms at municipal treatment plants can reduce the dissemination of pathogens to the environment and break the potential cycles of pathogen-associated infections.

In Canada, the disinfection of municipal wastewater treatment plant effluents is practised almost exclusively by chlorination. Although the process is capable of effecting a reduction in pathogenic micro-organisms when properly designed and operated, total elimination of disease-causing organisms does not occur. In addition, the process generates disinfectant residuals and byproducts at levels which may be toxic to aquatic life and, over the long term, may impact on human health.

In the environment, pathogenic micro-organisms eventually die off or are destroyed by natural processes. Their death is due to many influences including ambient temperature, the antagonistic actions of natural microbial life, exposure to ultraviolet radiation, predation, etc. When the time-interval between effluent discharge and use of the receiving environment by man is sufficient to allow natural elimination of the pathogens the need for disinfection is questionable . One key issue is the time required for natural purification in the environment, which depends on local site-specific factors.

Faced with the above, the Federal-Provincial Advisory Committee on Environmental and Occupational Health directed that a national working group be established to review current wastewater disinfection policies and practices in Canada and to recommend the policy and research needs required to maximize the human health and environmental benefits that may be realized through wastewater disinfection.

WASTEWATER DISINFECTION WORKING GROUP

On October 15, 1979, a Federal-Provincial Working Group on Wastewater Disinfection was formed with representatives from Newfoundland, New Brunswick, Nova Scotia, Ontario, Manitoba, Alberta, Northwest Territories, Health and Welfare Canada and Environment Canada. The federal representatives jointly acted as the secretariat for the Working Group, while the Ontario representative, Dr. P. Seto, was named Chairman.

The Federal-Provincial Working Group was charged with the responsibility of examining the need for and application of municipal wastewater disinfection, and, if necessary developing a methodology for evaluating the site-specific requirements for disinfection that would protect water uses, both from public health and environmental perspectives. In addition, a national inventory of past and ongoing research and development efforts was to be compiled, future research needs were to be identified, and a workable method of coordinating future research and dissemination of results and information was to be recommended.

During the two years that followed, the Working Group members met five times. Their deliberations were based mostly on the review of the vast amount of available literature as well as on the personal experience of the individual members in this field. Backup technical support was drawn from the participating provincial and federal agencies. In addition, several experts were invited to address the Group on selected topics and issues.

MAJOR FINDINGS OF THE WORKING GROUP

Major findings of the Working Group can be summarized as follows:

(1) The need for universal disinfection of municipal wastewater discharges to surface waters (i.e., freshwaters and marine waters) cannot be established using historical epidemiological evidence as a basis for support.

While there is an abundance of data confirming the existence of pathogenic micro-organisms in treated effluents, there is a lack of direct causal evidence linking such discharges to disease outbreaks except under conditions of heavy contamination with human wastes or during epidemic conditions. The Working Group concludes that there is an inadequate amount of epidemiological information to support a commitment to the practice of universal disinfection at all sewage treatment plants. Instead, the Group finds that the decision for "disinfection" or "no disinfection" of municipal discharges should be

established on a case-by-case basis taking into account jurisdictional requirements and the existing and potential uses of the receiving waters. The assessment should recognize health and environmental concerns and be based on effluent and water quality criteria and water use guidelines.

(2) Limited field evidence exists regarding the detrimental effects of disinfectant residuals and byproducts on the aquatic environment and human health in Canada.

An abundance of laboratory information exists which documents the acute and chronic effects of low-level residual chlorine concentrations on aquatic life. Field evidence that clearly indicates the negative impact of residual chlorine discharges on the Canadian environment is less abundant. Determination of the potential effects of disinfectant residuals and byproducts on the aquatic ecosystem has been a site-specific activity and, as such, the environmental benefits of reducing or eliminating such discharges on an across-the-board basis are impossible to quantify.

There is laboratory evidence that chlorinated organic compounds are formed during wastewater chlorination processes. Preliminary biological studies undertaken to determine the potential impact of some of these compounds on aquatic biota have revealed that minimal risk exists at the concentrations tested and under the conditions examined. Further research is required to fully address this question. Some chlorinated organics have been shown to have adverse effects on human health and therefore the need to fully research their formation, control and behaviour in the environment is apparent.

No other disinfectants and disinfection processes have been used at sewage treatment plants in Canada and therefore field information is not available on the environmental and health effects of other disinfection methods.

(3) There are two distinctively different administrative approaches in Canada for establishing the need for wastewater disinfection at municipal treatment plants.

There is agreement among the provinces that the need for wastewater disinfection is a site-specific requirement. However, two distinctively different administrative approaches are employed in Canada to achieve site-by-site specification. One approach requires disinfection of all municipal wastewater effluents; exemptions are granted to municipalities if they are able to show that there is minimal increased risk to human health as a result of the relaxation of disinfection requirements on a seasonal or on a year-round basis. The other approach involves case-by-case reviews by the responsible provincial agency to assess the increased risk posed to human health as a result of a

municipal wastewater discharge. Disinfection requirements may then be specified based on this case-by-case assessment. Each approach has evolved from different historical practices and administrative procedures.
Each approach is acceptable provided the review process affords medical and resource management authorities the opportunity for input to site-by-site specifications.

(4) Existing guidelines and/or standards for the design, operation and control of chlorination processes vary from province to province and in some cases may be inadequate to ensure effective reduction in levels of pathogenic micro-organisms and disinfectant residuals and byproducts in municipal wastewater effluents.

Criteria for the design, operation and control of wastewater chlorination processes vary from one provincial jurisdiction to another. Technology is available that provides the capability to practise wastewater chlorination in a manner that maximizes reduction in pathogen concentrations as well as providing protection to the aquatic ecosystem. Upgrading of existing design criteria and operational practices may be required by some jurisdictions in order to achieve these goals.

(5) Critical information on the need, application and effects of wastewater disinfection is lacking in several areas. Further research is required.

Federal and provincial health and environmental agencies have undertaken or supported research related to wastewater disinfection for a number of years. However, some critical research needs remain, including the optimization of process performance of alternate disinfectants, the use of microbiological indicators in wastewater effluents and in the environment and the formation and control of disinfection residuals and byproducts in the disinfection process.

WORKING GROUP RECOMMENDATIONS

Based on the deliberations and findings of the Working Group, the following major recommendations are made:

(1) In the absence of conclusive epidemiological evidence to support a national policy on universal wastewater disinfection or non-disinfection, the site-by-site review of disinfection requirements should be employed.

(2) A procedure should be developed and employed by each provincial agency to ensure the consistency and completeness of site assessments. The Working Group has

developed an evaluation procedure for site-by-site investigations and identified some key parameters considered essential for the evaluation. The procedure can be used for either imposition or relaxation of disinfection requirements.

(3) The disinfection process should be applied in a manner that ensures effective microbiological control. The definition of effective microbiological control in a treated wastewater effluent currently varies from jurisdiction to jurisdiction. Based on limited research in the area, it has been demonstrated that effluent with total coliform counts of 2 500/100 mL and fecal coliform levels of 200/100 mL can be consistently produced using current chlorination technology with nominal dosages and proper operating conditions. The Working Group considers the above levels reasonable objectives for effective disinfection. Site details and specific water uses, however, will dictate effluent disinfection requirements.

(4) A manual of practice on the design, operation and control of wastewater chlorination processes should be developed. Practical research information and technology related to the disinfection and post-disinfection detoxification of treated wastewater effluents should be collected and disseminated for the purpose of upgrading existing wastewater disinfection criteria and practices. As a first phase, the chlorination/dechlorination practice should be addressed.

(5) Research and data gathering related to the human health and environmental consequences of wastewater disinfection practices must be initiated and/or supported by federal and provincial agencies in order to provide a scientifically-sound information base for policy development. The areas of research which have been identified by the Working Group are: the research and development of scientifically-sound microbiological standards for human health protection; the survival and regrowth potential of pathogens in the environment; the formation of toxic chemicals in wastewater disinfection processes; disinfection alternatives to wastewater chlorination; resistance transferable R-factors in coliforms and fecal coliforms; the survival of indicator and pathogenic micro-organisms in sewage lagoons; the effectiveness of chlorination processes in virus removal; methods of detection of viruses and parasites; the development of reliable low level chlorine residue measurement methodology and equipment; the application of storage ponds for the dechlorination of wastewater effluents; and the optimization of the disinfection of primary effluents. In addition, the national reporting system for waterborne

diseases should be further developed to provide a reliable Canadian data base for related epidemiological studies.

(6) Resource management and environmental agencies should continue to document field observations and develop case histories that demonstrate the effects of disinfectant residuals and byproducts on aquatic life and their habitat. This work would complement existing (and future) laboratory studies and serve to determine the applicability of laboratory data to actual field conditions.

(7) A standing body comprised of federal and provincial representatives from environmental and public health agencies should be organized to identify, priorize, coordinate and monitor the research needs associated with wastewater disinfection, as well as to disseminate research information for practical application in this country. Central agencies (e.g., Health and Welfare Canada and Environment Canada) should assume responsibility for managing this program and use the proposed federal/provincial group in a technical advisory role.

MEMBERS OF THE FEDERAL-PROVINCIAL WORKING GROUP ON WASTEWATER DISINFECTION

CHAIRMAN Ontario Representative	Dr. P. Seto, Head, Municipal Sewage Unit, Pollution Control Branch, Ministry of the Environment, 40 St. Clair Avenue, West, Toronto, Ontario.
SECRETARIAT Department of National Health and Welfare Representative	Ms. V.M. Douglas, Chemist, Monitoring and Criteria Division, Environmental Health Centre, Tunney's Pasture, Ottawa, Ontario. K1A 0L2
Department of Environment Representative	Mr. D.J. Hay, Senior Program Engineer, Municipal Division, Abatement and Compliance Branch, Environment Canada, Water Pollution Control Directorate, Ottawa, Ontario K1A 1C8

PROVINCIAL REPRESENTATIVES:

Alberta:	Mr. David Spink, Head, Special Projects Section, Municipal Engineering Branch, Standards and Approvals Division, 5th Floor, Oxbridge Place, 9820-106th Street, Edmonton, Alberta. T4K 2J6
Manitoba:	Mr. Kelly Kjartanson, Environmental Control Services Branch, Manitoba Department of Environment, Box 7, 139 Tuxedo Avenue, Winnipeg, Manitoba. R3C 0V8

New Brunswick:	Mr. P.M. Tracey, Microbiologist, Regional Laboratory, Department of Health, 8 Castle Street, Saint John, New Brunswick. E2L 3B8
Newfoundland:	Mr. K. Dominie, Environment Engineer, Department of Consumer Affairs and Environment, 100 Elizabeth Avenue, Elizabeth Towers, St. John's, Newfoundland.
Nova Scotia:	Mr. P.J. Casey, Director, Division of Public Health Engineering, Department of Health, P.O. Box 488, Halifax, Nova Scotia. B3J 2R8
Northwest Territories:	Mr. Vern Christensen, Head, Water and Sanitation Section, Town Planning and Lands Division, Department of Local Government, Government of Northwest Territories, Yellowknife, Northwest Territories. X0E 1H0

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1. INTRODUCTION

1.1 Background and Objectives of the Working Group

At the March 1979 meeting of the Federal Provincial Advisory Committee on Environmental and Occupational Health, the federal Departments of National Health and Welfare and Environment presented a brief on current Canadian practices and policies for municipal wastewater disinfection. The purpose of the brief was to outline some of the inadequacies and problem areas associated with wastewater disinfection as practised in Canada and to recommend a joint Federal-Provincial review of the situation.

In response to the brief, the Advisory Committee directed that a national working group be established to address the following subjects (direct quote):

1. the need and application of disinfection of municipal wastewater effluents (including discharge to both freshwater and marine environments);
2. a framework for site-specific requirements necessary to ensure the maintenance of desired water uses while protecting public health and minimizing adverse environmental impact;
3. current and historical research and development efforts and future research and information needs;
4. ways to coordinate research and to ensure better practical application of the results of such research.

On October 15, 1979, the first meeting of the Federal-Provincial Working Group on Wastewater Disinfection convened in Ottawa, with technical representation from Newfoundland, New Brunswick, Nova Scotia, Ontario, Manitoba, Alberta, Northwest Territories, Health and Welfare Canada, and Environment Canada. The federal representatives also acted as secretariat for the Working Group.

1.2 Working Group Approach

In addressing the assigned tasks 1 and 2, the committee reviewed a wide range of water-use practices and assessed the impact of current and proposed wastewater disinfection practices on those uses. An evaluation matrix was developed (Figure 1) by the committee and this matrix afforded representatives in the Working Group the opportunity to compare prescribed limits and guidelines for municipal wastewater discharges and to evaluate their applicability to water use criteria in a provincial, as well

TYPE OF DISCHARGE \ WATER USE	GENERAL AMBIENT	RECREATION	RAW DRINKING WATER	FISHERIES: (SHELLFISH, VERTEBRATES)	IRRIGATION: (AGRICULTURE, RECREATION)	OTHER USES
STORMWATER						
COMBINED SEWER DISCHARGES						
SANITARY: RAW SEWAGE						
SANITARY: PRIMARY EFFLUENT						
SANITARY: SECONDARY EFFLUENT						
SANITARY: LAGOON EFFLUENT						
INDUSTRIAL WASTES						

Figure 1

WATER QUALITY EVALUATION MATRIX FOR VARIOUS WATER USES AND WASTEWATER SOURCES

as national context. Ultimately a "decision-tree" was developed to aid in site-specific evaluations.

An inventory of wastewater disinfection related research and development efforts, including past, current and proposed projects, was completed by the Working Group with each representative canvassing scientific and educational institutions in their respective province/territory. The Secretariat contacted provincial agencies not participating in the Working Group and determined their research activities and needs.

Finally, the question of better ways to coordinate research of this nature on a national basis, and to disseminate the resulting knowledge and information, was resolved through discussion with research agencies and in-committee.

2. EXISTING PRACTICES

In Canada, approximately 11 x 10^6 m^3 of municipal wastewater (not including stormwater) are discharged to the environment daily. About 6 x 10^6 m^3/d of this wastewater receives some form of treatment: 17% by conventional primary treatment; 83% by secondary or tertiary treatment processes. Of the treated volume, 4 x 10^6 m^3/d is disinfected (approximately 35% of the total wastewater flow or 67% of the treated wastewater flow). Disinfection is almost exclusively by chlorination (Canada, 1978).

Approximately 8000 tonnes of chlorine were used in 1978 by municipalities in Canada for water and wastewater disinfection (International Joint Commission (IJC), 1980a). This represents 1% of the total annual national consumption of chlorine (Statistics Canada, 1977). Table 1 lists other chlorine consumers and indicates that the pulp and paper industry and the industrial chemical industry are the major users of chlorine (95% to 99% of total consumption). Not shown in Table 1 are power plants which use approximately 26 tonnes of chlorine annually for in-system biofouling control (Dearborne, 1976).

The use of chlorine for wastewater disinfection has been the subject of numerous reports and controversy in recent years. The controversy is focused on the relative benefits of wastewater chlorination in terms of public health protection versus the consequences of discharging residual chlorine and chlorinated organics to surface waters. While it is evident that municipal wastewater discharges do pose a risk to public health, the degree of risk is a function of receiving water use and several other site-specific variables. It is also evident that chlorine may kill fish and other aquatic organisms when discharged into their aquatic habitat; the level of impact is a function of concentration, period of exposure and several other site-specific variables. Eliminating or curtailing the practice of wastewater chlorination would reduce or eliminate the potential for detrimental effects to fish and aquatic life, reduce the discharge of chloro-organic compounds and result in financial savings to municipalities which operate sewage treatment plants. However, health risks would increase and in some cases, specific water quality criteria or water use guidelines may be violated. As an alternative to the curtailment of wastewater chlorination, it should be noted that the adverse effects on aquatic life may also be eliminated or reduced by the dechlorination of chlorinated effluents. The degree to which public health and the environment may be affected as a consequence of changing or updating existing disinfection practices is examined in subsequent chapters.

TABLE 1 CHLORINE PRODUCTION AND CONSUMPTION IN CANADA (IJC, 1980a)+

	1973[1]	1975[1]	1976[2]
Total Production (metric tonnes)	889 948	748 894	898 336
Total Consumption of Industries Surveyed (metric tonnes)	818 330	604 787	792 815
Consuming Sectors	% Consumption by Industries Surveyed*		
Municipal Waterworks	.7	1.0	-
Mining	.6	0.8	-
Pulp and Paper	57.3	83.5	62.4
Smelting and Refining	.9	1.2	-
Soap and Cleaning Compounds	1.1	1.2	0.9
Industrial Chemicals	39.4	12.0	36.6
Fish Processing	-	-	0.02
Miscellaneous Food Industries	-	-	0.01
Miscellaneous	0.1	0.3	0.07
	100.1	100.0	100.0

+ This table does not include the consumption by wastewater treatment plants, which is considered to be about 1% of total consumption. See text.

* Only certain users are surveyed each year. In 1976, municipal waterworks, mining, and smelting and refining were not surveyed. These users did, however, use chlorine during that year.

1 Statistics Canada, (1977).

2 Dornan, J. (1979).

2.1 Chlorination Practices

In Canada, individual provinces and territories specify design and control parameters for wastewater chlorination processes. These criteria are listed in Table 2, along with the microbiological criteria that each jurisdiction has adopted as indicating an acceptable degree of disinfection. While the criteria differ from one jurisdiction to the next, the common objective is the destruction of pathogens. Based on limited research in the area, it has been demonstrated that effluent with total coliform counts of 2 500/100 mL and fecal coliform levels of 200/100 mL can be consistently produced using current chlorination technology with nominal dosages and proper operating conditions. The Working Group considers the above levels reasonable objectives for effective disinfection. Site details and specific water uses, however, will dictate effluent disinfection requirements.

The question of whether or not the design criteria listed in Table 2 result in the generation of a microbiologically "safe" effluent is difficult to answer in a general manner. Sewage treatment plants utilize a variety of processes that have varying treatment capabilities and produce varying qualities of effluents. Effluent quality affects the efficiency of the disinfection process; ammonia and other nitrogenous compounds, organic constituents such as phenols, and inorganic reducing agents such as sulphur compounds, iron and manganese all reduce the effectiveness of chlorination processes (Environmental Protection Service (EPS), 1978a; Water Pollution Control Federation (WPCF), 1976; White, 1972). Clarke et al (1964) determined that a contact period of at least 100 minutes is required to achieve a 99% reduction of E. coli. in treated effluents. White (1974) conducted an investigation into disinfection practices at 26 California treatment plants during a six-month period (primary, secondary and tertiary treatment systems). His data indicated that chlorination of both primary and secondary plant effluents resulted in low total coliform counts (10/100mL), providing the following conditions were met:

1) Good initial mixing was of major importance, particularly if chlorine demand was high.
2) Optimum total residuals were 3 to 4 mg/L after a minimum of 30 minutes contact for an initial chlorine demand of 15 mg/L. For demands greater than 15 mg/L residuals of 7 to 10 mg/L were required.
3) Contact chambers had a "plug-flow" regime with little or no backmixing.

TABLE 2 MICROBIOLOGICAL CRITERIA AND DESIGN PARAMETERS FOR WASTEWATER DISINFECTION SYSTEMS IN CANADA

	Effluent Criteria		Chlorine Process Design		
	T.C. Organisms 100mL	F.C.	Chlorine Residual (TRC) (ppm)	Contact Time (minutes)	Method of TRC Measurement
+ Newfoundland[1]	5000	1000	1.0	30	
+ New Brunswick[2]	-	-	0.5	20-30	D.P.D.
+ Nova Scotia[3]	5000	-	0.5		
+ Ontario[4]	2500 (avg.) 5000 (max.)	200	1.5* 0.7-1.2**	30	D.P.D. or Amperometric
++ Manitoba[5]		200			D.P.D.
++ Alberta[6]			2.0	20	-
++ Northwest Territories[7]			1.0	15	-
+ Federal Installations[8]		400	0.5 to 1.0	30	

D.P.D. - diethyl-p-phenylene diamine
F.C. - fecal coliform
T.C. - total coliform
TRC - total residual chlorine

1. Newfoundland Dept. of Consumer Affairs and Environment; Environmental Control (Water and Sewage) Guidelines for Design, Construction and Operation of Water and Sewage Systems, 1980. Regulations, 190; Reg. 156-80.
2. Environment New Brunswick; Guidelines for the Collection and Treatment of Wastewater; May 31, 1979.
3. Nova Scotia Department of Health, In-house guidelines.
4. Ontario Ministry of Environment; Proposed Policy on the Disinfection of WPCP Effluents in Ontario, Draft No. 3, September, 1980.
5. Manitoba Dept. of Consumer and Corporate Affairs and Environment. In-house Departmental guidelines.
6. Alberta Environment; Recommended Standards for Water Supply and Sewage (April, 1978)
7. Northwest Territories Public Health Ordinance
8. Environment Canada; Guidelines for Effluent Quality and Wastewater Treatment at Federal Establishments; Report EPS-1-EC-76-1, April 1976.

* Recommended for primary effluents.
** Recommended for secondary effluents.
\+ Across the board disinfection - with site-specific relaxation allowed
++ Site-specific resolution.

4) Chlorine residual control was provided. (Measurement should preferably be by an amperometric technique; the orthotolidine method should not be used with wastewater.)

White's study concluded that the most effective disinfection was achieved by plants with long outfalls that ensured prolonged contact times. Circular and rectangular chambers were subject to short circuiting and even baffled rectangular basins required higher chlorine residuals to achieve results comparable to plants with outfalls. The obvious implication arising from these reports is that design criteria employed in the construction of existing chlorination facilities, in most cases, may be inadequate.

In addition to design problems, chlorine residual measurement and operational problems associated with disinfection processes have also been examined (EPS 1978a General Accounting Office (GAO), 1977). The acid-orthotolidine method (OT) for residual chlorine analysis in chlorinated effluents is not recommended for use because of its poor accuracy, precision and high overall total error. The OT methods have been deleted from the 15th edition of Standard Methods. The DPD test (diethyl-p-phenylene diamine) (Palin, 1957) and the amperometric titration methods of residual chlorine analyses are now widely used in the field and in laboratories. In addition to the difficulty in measuring chlorine residual levels in plant effluents, there is the problem of operator perception of the chlorine disinfection process. Rather than risk the possibility of violating microbiological limits, either in the effluent or in the receiving environment, operators may over-chlorinate discharges (EPS, 1978). Over-chlorination combined with fluctuations in plant flows and chlorine demands during the day, often result in the discharge of excessively high levels of chlorine into the receiving environment. To avoid or limit such occurrences, chlorine control systems/procedures have been developed and some treatment plants have incorporated these systems into their operations.

2.2 Sources of Bacteriological Contamination and Their Control

The goal of wastewater disinfection is to control bacteriological contamination. Figure 2 identifies a number of known sources of bacteriological contamination to surface waters. The list includes:

- municipal wastewater treatment plants
- stormwater discharges
- combined sewer overflows

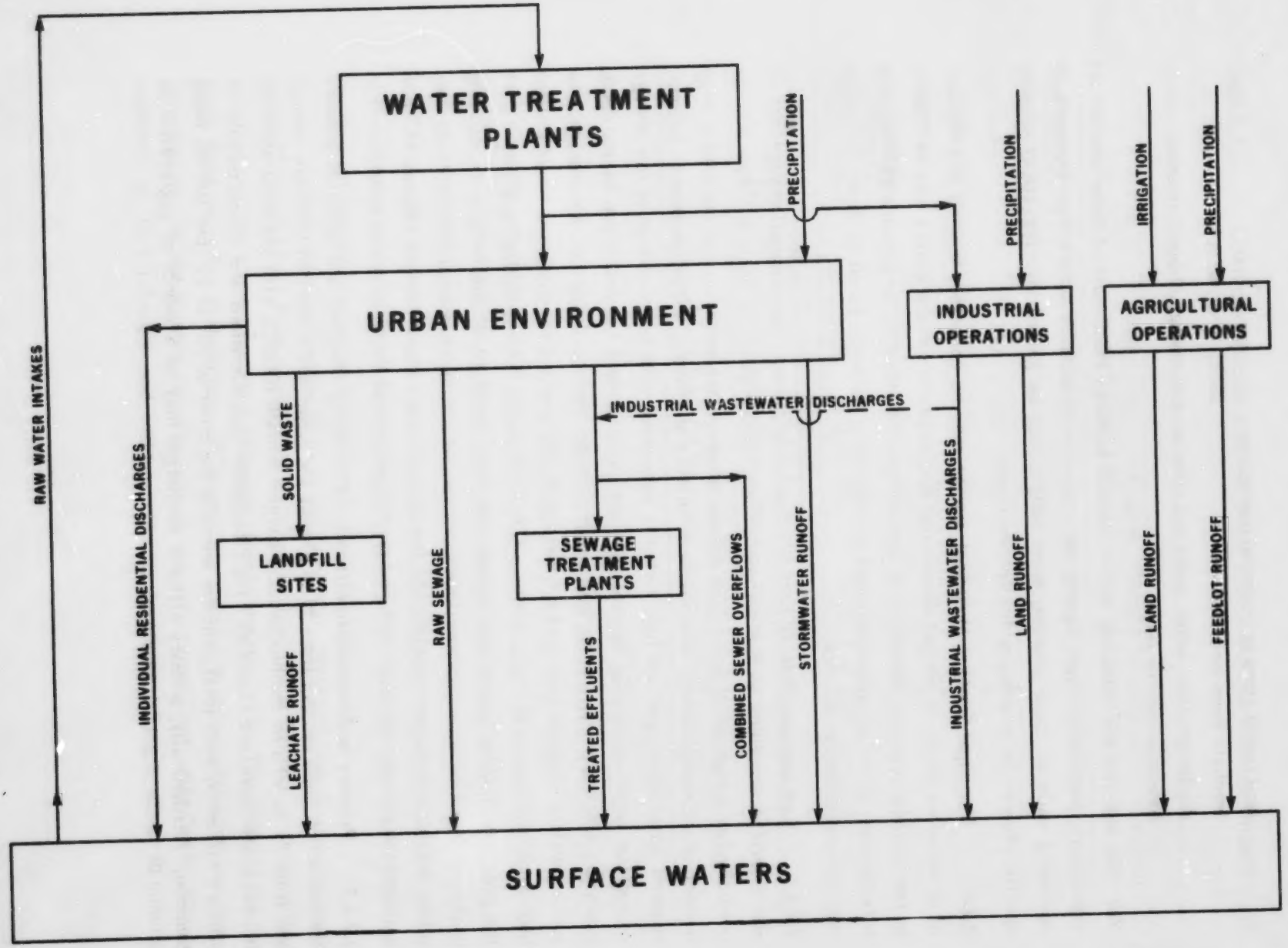

FIGURE 2 SOURCES OF BACTERIAL CONTAMINATION TO SURFACE WATERS

- land runoff from agricultural operations
- leachate from landfill sites
- discharges from septic tanks and other on-site sewage disposal systems
- industrial discharges

The flow volumes and resulting bacteriological loadings from most of these sources are significant. Nationally, these figures are impossible to quantify accurately. However, by reviewing each of these sources, some insight may be gained into the utility of site-specific reviews for evaluating disinfection needs.

2.2.1 Municipal Sewage. Municipal sewage may be collected, treated and disposed of in numerous ways. Municipal wastewater discharges to surface waters may be classed as raw sewage; primary, secondary or tertiary treated effluents, or lagoon effluents. The effectiveness of chlorination processes in controlling bacterial levels in these discharges may be summarized as follows:

2.2.1.1 Raw sewage. Raw or partially treated (screened, comminuted) sewage may be characterized according to the parameters and levels listed in Table 3. Raw sewage normally has a high solids and a high soluble organics concentration and contains a large number of microorganisms. The aesthetic effects of floating solids, sediment buildup, reduced dissolved oxygen and high turbidity associated with the discharge of raw sewage to surface waters generally dictate that the pretreatment of discharges be provided. However, there are many municipalities in Canada that do discharge raw sewage into surface waters. Disinfection of raw sewage with chlorine in these instances would involve high chlorine dosages (30 mg/L, White, 1972; 15-16 mg/L, Bohin, 1980). For the most part the practice of chlorinating raw sewage has been found to be ineffective in reducing bacterial densities to acceptable levels because of the many natural interferences (i.e. solids, organics, hydrogen sulphide) and the large numbers and behaviour (White, 1978) of pathogens in raw sewage which reduce the effectiveness of the disinfection process.

2.2.1.2 Primary (sedimentation) effluent. Efficiently designed and operated primary sedimentation tanks remove from 50 to 65% of the suspended solids (SS) from raw sewage and from 25 to 40% of the biochemical oxygen demand (BOD_5); with chemical addition, removals are increased (Table 3). High bacterial concentrations are characteristic of primary effluents, with total coliform levels in the order of 10^6 to 10^7 per 100 mL being common. Aesthetically, primary effluent discharges may be a source of aggravation to

TABLE 3 COMPOSITION OF SEWAGE AND STORM WATER (Canada-Ontario Agreement, 1980)

	BOD (mg/L)	SS (mg/L)	Total N (mg/L)	Total P (mg/L)	Total Coliform (per 100 mL)	Fecal[3,4] Coliform (per 100 mL)
Raw Sewage (1)	165	225	30	6.5	10^8	10^7
Treated Sewage (1)						
- Primary	100	100	30	6.5	10^8	10^7
- Primary (P removal)	50	50	22	1.0	10^7	10^6
- Secondary	17	23	18	1.0	10^6	10^5
Combined Sewer Overflow (2)	44	190	83	1.4	10^7	10^6
Surface Runoff	14	170	35	0.35	2×10^4	5×10^3

Notes:
(1) Measured flow-weighted mean
(2) Calculated flow-weighted mean for Ontario Great Lakes communities.
(3) These values are representative of values recorded in Canadian and U.S. communities.
(4) Note - Ontario Total Body Contact Recreational Standards: Total Coliforms 10^3 per 100 mL; Fecal Coliforms 10^2 per 100 mL.

local water users because debris, oil, scum, colour, odor or turbidity are sometimes associated with such effluents. Primary effluents may also be acutely toxic to fish and other aquatic organisms in receiving waters (Martens and Servizi, 1976).

The disinfection of primary effluents is a topic that has not been well researched by provincial and federal agencies. Though actual data is limited, experience indicates that substances which interfere with efficient chlorine utilization (e.g. organics, solids, hydrogen sulphide) occur more frequently and at higher concentrations in primary effluents than in chemically-treated primary effluents (i.e. primary plants with phosphorus removal processes) or secondary effluent. (Sproul, 1977).

High chlorine dosages (8 to 18 mg/L) (WPCF, 1976) and high residual chlorine levels (2.5 mg/L) have been proposed as a means of obtaining acceptable end-of-contact coliform concentrations in primary effluents (Tonelli and Ho, 1979). This proposal has not been field tested. Disinfection of chemically-treated primary effluents has been investigated. At the Windsor, Ontario, main primary treatment plant, using ferric chloride additions of 16 ± 1.5 mg/L and residual chlorine levels of 1.3 mg/L after 30 minutes

contact time, the total coliform survival densities were maintained below 4000 counts/100 mL (Tonelli and Ho, 1979).

It has been suggested that disinfection criteria for primary treatment plants be tested and established on a case-by-case basis. If a target total coliform level cannot be consistently achieved using excessive chlorine dosages (more than 25 mg/L) or excessive end-of-contact residual (more than 2.5 mg/L total residual chlorine) then upgrading of treatment facilities or disinfection facilities should be considered (Ontario MOE, 1980).

2.2.1.3 Secondary (biological) and tertiary effluent. A well-operated, and well-designed biological wastewater treatment plant is capable of producing an effluent that is characterized by low BOD and SS levels and that has concentrations of total coliform in the 10^5 to 10^6 per 100 mL range (Table 3). In most cases fecal coliforms are about one order of magnitude lower than total coliforms. Effluents from this type of plant are normally aesthetically inoffensive.

The removal of solids, soluble organics and other interfering agents by a secondary treatment system enhances the effectiveness of disinfection processes. Total and fecal coliform reductions of 2 to 3 orders of magnitude are achieveable with the present chlorination processes. The final counts for total and fecal coliforms would therefore be at or close to 2500/100 mL and 200/100 mL, respectively, and thus meet the desirable objectives recommended for efficient disinfection processes (Ontario Ministry of the Environment (MOE, 1980a).

2.2.1.4 Lagoon effluent. The quality of effluent discharging from a lagoon system varies with seasonal influences, process design and mode of operation. Four types of lagoons are commonly used in Canada, namely: aerobic; anaerobic; facultative; and aerated, with each type having a characteristic effluent.

Discharges from an anaerobic lagoon contain high SS concentrations (80-160 mg/L) and BOD_5 values in the 40 to 120 mg/L range. An aerobic pond, a facultative pond, an aerated cell, or a combination thereof, located downstream from an anaerobic lagoon system can improve the quality of the effluent prior to discharge (Dawson et al, 1973).

Effluent from a facultative lagoon system is characterized by BOD_5 levels in the 10 to 40 mg/L range and SS concentrations of 20 to 400 mg/L. High solids levels (ie. 400 mg/L) in facultative lagoon effluents may occur for a short period of time during

summer months as a result of flourishing algae populations in the ponds. Multi-cell facultative lagoon systems are frequently employed to reduce the algae loadings in continuous discharge situations or to produce higher quality effluents. Lagoons may also be discharged seasonally in the spring and/ or fall of each year when the algae population is minimal.

An aerated lagoon is a flow-through aerated basin that discharges effluent continuously. Aerated lagoons are capable of producing effluents containing 20 to 60 mg/L of BOD_5 and 30 to 170 mg/L of SS. Oftentimes, in order to facilitate settling of biological solids, facultative ponds may follow aerated cells.

Bacteriological levels in facultative and aerated lagoon systems vary depending on temperature, retention time, number of cells, flow pattern, plant growth, pH, nutrient levels and microbial antagonism. The options available to reduce bacterial levels are generally restricted to retention, number of cells or disinfection.

The effect retention time can have on bacterial die-off in a lagoon system has been investigated. Marais (1974) and Bowles et al, 1979, have used Chick's law ($dN/dt = KN$) to describe the die-off of fecal bacteria in lagoon systems. For a lagoon system, retention time is inversely proportional to organic loading and a number of investigators reported reduced fecal bacteria die-off at higher organic loadings (Neel et al, 1961; Geldreich et al, 1964; and Gann et al, 1968). Parker (1962), in a study of anaerobic, single-cell aerobic and multi-cell aerobic ponds in Australia, reported that short circuiting increased effluent fecal bacteria counts. Total hydraulic retention times for lagoon systems ranging from 80 days to 147 days have been predicted to give effluent total coliform counts of less than 100/100 mL (Meron et al, 1965; Oswald et al, 1967; and Bowles et al, 1979). Results of a 1971 laboratory study by Berg (Table 4) indicate that a 99.9% reduction of various viruses and bacteria is achievable throughout the year provided sufficient storage time is available. Other investigators have confirmed these effects in laboratory and field studies (Malina and Sagik, 1974; Borchardt et al, 1977; Berg, 1971). To achieve consistent effluent bacterial quality, winter conditions should be used for determining retention requirements in lagoon design, provided the same degree of bacterial reduction is required during the winter as during the summer periods.

The number of cells in a lagoon system and the flow pattern in each cell will also affect bacteriological levels in lagoon effluents. Franzmathes (1970), in a review of lagoon fecal bacteria data, reported that there was no apparent relationship to either normal loading or theoretical retention time and bacterial reduction, but that the

TABLE 4 EFFECTIVE STORAGE. LABORATORY STUDY DEMONSTRATING DAYS REQUIRED FOR 99.9% REDUCTION OF VIRUSES AND BACTERIA IN SEWAGE (BERG, 1971).

	Number of Days Required		
Organisms	4°C	20°C	28°C
Poliovirus 1	110	23	17
Echovirus 7	130	41	28
Echovirus 12	60	32	20
Coxsackie A9	12	--	6
Aer. aerogenes	56	21	10
E. coli	48	20	12
Strep. faecalis	48	26	14

number of ponds was significant. Parker (1962), reported that is was difficult to obtain very low coliform counts from single cell ponds and Shindals and Mahlock (1974) in a study of a 3-cell waste-stabilization system in Jackson, Mississippi, concluded that the main benefit of the 2nd and 3rd cells of the system were in the area of bacterial reduction. Hoshi et al, (1973), in a study of two lagoon systems in Nagpur, India, reported higher reductions of coliform bacteria and Salmonella in a 3-cell pond system than a 2-cell pond system, even though the 2-cell pond system had a lower organic loading and greater theoretical retention than the 3-cell system. The kinetic fecal bacterial model for lagoon system proposed by Marais (1974) predict greater bacterial reductions for a series of ponds than for a single completely mixed pond when each pond system provides the same total hydraulic retention time. Marais' kinetic model predicts that maximum bacterial reduction efficiency in a series pond system is achieved by making the retention times in all ponds the same. Marais (1974) also reported that, per unit of retention time, the plug flow system is the most efficient in reducing bacteria.

The interrelationship of temperature, retention time and lagoon configuration on bacterial die-off in lagoon systems makes it impossible to accurately specify a retention time that will result in a specific bacterial effluent quality. Lagoon retentions and configurations producing the desired level of bacterial reduction can, therefore, only

be determined by actual field monitoring, with results applicable only to similar lagoon systems in similar geographic/climatic areas.

In Canada, in short retention situations (i.e. 30 days storage or thereabouts), disinfection of the lagoon discharge will normally be required to achieve consistent bacterial reduction. The chlorination of a lagoon effluent may be complicated by the presence of high concentrations of algae during the summer periods. Algae increase chlorine demand and this, in turn, means higher initial doses of chlorine are required to produce the desired degree of disinfection. Considerable controversy exists over the ability to disinfect lagoon effluents adequately. Conflicting opinions concerning the need for algae removal (i.e. filtration) prior to disinfection exist (Environmental Protection Agency (EPA), 1979). However, it has been proposed (Black and Vajdic, 1979) that if lagoon effluent suspended solids can be maintained at 60 mg/L or less, then effluent disinfection can be an efficient practice.

One final consideration in the discussion of lagoon effluents is the effect that chemical addition can have on effluent quality. In Ontario, phosphorus removal practices for lagoon discharges have been shown to enhance the reduction of coliform levels (Graham and Hunsinger, 1974). It may be concluded, based upon experience with chemical addition to mechanical plants, that this practice will also enhance the inherent reduction of pathogenic organisms in sewage lagoons and possibly even eliminate the need for disinfection.

2.2.2 Stormwater Discharges. Public sewer collection systems serve 17.4 million Canadians (Canada, 1981), with 64% of these people residing in municipalities which are totally or in part serviced by separate storm collection systems.

BOD and nutrient concentrations in stormwater discharges are on an average lower than those in raw or treated sewage discharges, but suspended solids concentrations approach levels found in raw and combined sewage. Total coliform concentrations, although low in comparison to values in treated wastewaters, (eg. 20 000/100 mL), may cause receiving water quality standards or objectives to be exceeded. As an example, the deterioration of the bacteriological quality of the Rideau River in and around Ottawa has been attributed to surface runoff from urbanized areas (EPS, 1980). Other examples have also been documented (Canada-Ontario Agreement (COA), 1978a). The correlation between indicator organisms (i.e. total coliforms and fecal coliforms) and pathogens in stormwater runoff is not well researched or resolved, although the presence of pathogenic

organisms has been verified. The results of three feasibility studies in Ontario (COA, 1978a) indicated that fecal pollution in the separate storm systems examined was predominantly of non-human origin. Fecal material from animals and birds washed into the system during rain storms appeared to be the major source of the microbial populations identified. The potential for the presence of pathogenic organisms in stormwater runoff exists, however, regardless of the source of fecal pollution.

Reductions in bacteriological loadings in urban runoff have been accomplished through the use of holding ponds, catch basin maintenance programs and street sweeping operations. However, the utility of employing these practices solely for the purpose of controlling bacterial levels in receiving waters would have to be assessed on a site-specific basis to ensure that the end result justified the expenditure involved.

Disinfection of stormwater is not widely practised in Canada as a means of controlling bacterial levels in receiving waters. Process control limitations, costs, the potential for environmental damage and the intermittent nature and unpredictable microbiological quality of stormwater discharges all mitigate against any policy of universal disinfection of stormwater. A more realistic and practical solution in local situations may be to treat those separate storm sewers identified as problems. Pretreatment of the runoff (i.e. solids removal) prior to discharge may preclude the need for disinfection or at least enhance the effect of the disinfecting agent should such action be necessary.

2.2.3 Combined Sewers. Combined sewers (i.e. sewers which carry runoff from house drains, sanitary wastewater and stormwater) serve a total of 6.4 million persons in Canada (Canada, 1981), mostly in highly urbanized downtown areas of large municipalities.

Combined sewer overflows (CSO) discharging into a body of water can have a detrimental effect on the quality of such waters and their intended use. Total coliform concentrations in the order of 10^7/100 mL (fecal coliforms 10^6/100 mL) are characteristic of effluents of this nature. In addition, high BOD_5 and suspended solids levels, turbidity and floating debris are among the aesthetic unpleasantries commonly associated with CSO discharges (Table 3).

The general quality of a CSO is somewhat similar to a raw sewage discharge and as such the utility of disinfecting the overflow without some form of pretreatment is questionable. Although the bacterial load associated with CSOs in Canada has never been

calculated, it has been estimated that the annual contribution approximates that from continuous municipal discharges (Buxton, 1975).

Where CSO discharges are found to be a significant problem, existing combined sewers can be separated or provided with increased capacity, through in-line and off-line storage or construction of interceptors to the sewage treatment plant. The objective in either case is the reduction in the number of overflows that occur on an annual basis. The cost of these upgrading efforts must be balanced against the reductions in public health risk and environmental damage that will result by reducing the number of CSOs. The cost of reducing risk and damage (reducing overflows) increases exponentially as the level of overflow control increases.

2.2.4 Other Non-Point Discharges. Agricultural and rural runoff, discharges from septic tanks and tile fields, and leachate from landfill sites are difficult to quantify in terms of annual volumes or pollutant loadings to the environment, simply because this information is difficult to generate and therefore existing documentation is limited. Several reports, most of which are site specific in nature, define the quality of effluents from these sources (Engelbrecht et al, 1974; Brandes, 1978; PLUARG, 1978). Table 5 shows the range of pollutant concentrations of these non-point discharges. As is evident, the acute lethality of these discharges to flora and fauna in receiving waters would be a concern.

The significance of non-point discharges must be assessed on a site-by-site basis to determine their relative impact on receiving waters.

2.2.5 Industrial Effluents. Industries may also be sources of wastewater discharges containing bacteriological contaminants.

The food processing industry and the pulp and paper industry are two major industrial sources of bacterially contaminated discharges. In particular, meat and poultry plant effluents have been found to contain high concentrations of Salmonella, (EPS, 1976; EPS, 1978b; Vanderpost and Bell, 1977), while the pathogen Klebsiella has been found in pulp and paper plant effluents (Bell et al, 1978; Huntley et al, 1976; BC Research, 1971). As discussed earlier, control options for such discharges must be addressed by local jurisdictions. It is emphasized, however, that unless the effluents being discharged are treated in an acceptable manner, the effectiveness of current disinfection processes in removing pathogens is limited. Further, the practicability of disinfecting a municipal

TABLE 5 TYPICAL EFFLUENT CHARACTERISTICS FROM NON-POINT SOURCES OF BACTERIAL CONTAMINATION TO SURFACE WATERS

	Agricultural Runoff (mg/L)	Landfill Leachate (Engelbrecht et al, 1974) (mg/L)	Septic Tank Discharges (Brandes, 1978) (mg/L)
BOD_5	400-7900	variable	30-300
COD	1900-78000	0-89500	75-1420
TSS	1100-13500	1000-45000*	30-760
NH_3-N	0-2000	0-1100	9-160
pH	4.5-9.5	3.5-8.5	7.2-7.7
Total Coliforms[t]	**	$0-3.5 \times 10^5$	$0.4-8.1 \times 10^6$
Fecal Coliforms[t]	**	$0-3.0 \times 10^3$	$0.1-1.9 \times 10^6$
Fecal Streptococci[t]	**	$0-4.5 \times 10^5$	-

t organisms/100 mL
* total solids concentration
COD Chemical Oxygen Demand
TSS Total Suspended Solids
** Highly variable. Even with ungrazed fields, run off quality could exceed bathing water criteria (eg. 1 000 TC/100 mL) over 50% of the time (Burgh et al, 1980).

wastewater discharge, while disregarding the pathogen load from a nearby industrial source and its impact on public health, is questionable.

2.3 Bacteriological Limits in the Ambient Environment

The discharge of wastewater effluents to receiving waters, onto land or to subsurface soils is governed by guidelines and objectives which are normally categorized according to receiving water or receiving land use. In the case of surface waters, ambient water quality objectives take the form of indicator bacterial limits. For land uses, the application of wastewater is governed by preapplication treatment, design and operational guidelines. The main water and land uses for which control criteria are stipulated are raw water supply, recreation, shellfishing, agriculture (irrigation) and industry.

2.3.1 Surface Waters. The most common method of wastewater effluent disposal is discharge to surface waters. The coliform group of bacteria historically has been used as an indicator of bacteriological contamination in surface waters. At present, regulatory agencies use either total coliforms, fecal coliforms, or both, as a measure of the public health risk associated with water use. Table 6 lists surface water microbiological criteria that are employed in Canada.

A commentary on the problems associated with the use of indicator organisms such as the coliform group in the aquatic environment is presented in Section 3. In general, however, it appears that indicators will be used as measures of bacteriological water quality until more direct and reliable methods are devised.

2.3.2 Surface Land Disposal. Criteria differ from province to province on the acceptability of wastewater effluents for irrigation of agricultural lands. Some provincial agencies allow primary effluents to be applied to agricultural lands except in cases where the crops being grown are for human consumption or where public accessibility is a potential problem. In these instances, effluents from properly operated secondary treatment plants, effluents or lagoon systems with specified detention capacity, or disinfected secondary effluents, are required. Currently, sewage effluents are not being used for irrigation of food crops which are directly consumed by the public. The rationale for avoiding this practice is that surface water is available and there is no need in Canada to take the risk associated with wastewater irrigation of such crops.

The use of primary treated wastewater effluents for irrigation of recreational lands (e.g. parks, golf courses) or lands to which the public has uncontrolled access is not

TABLE 6 MICROBIOLOGICAL CRITERIA FOR SURFACE WATERS

Province	Raw Water Supply		Freshwater Recreation (Primary Contact)		Marine (Shellfish)
	TC/100 mL	FC/100 mL	TC/100 mL	FC/100 mL	FC/100 mL
Newfoundland	Federal Guidelines**		500	200	14
New Brunswick	Federal Guidelines**		-	200	14
Nova Scotia				200	14
Ontario	*	*	1000	100	
Manitoba	5000	1000	500	200	
Saskatchewan	5000	1000	1000	200	
Alberta	5000	1000	1000	200	
Northwest Territories	Federal Guidelines**		1000	100	14

* Microbiological limits are not specified for raw water supply, provided full treatment is applied. Minimum treatment for surface water supply, for example, is coagulation, filtration and disinfection (Ontario MOE).

** Health and Welfare Canada (1978). Guidelines for Canadian Drinking Water Quality.

generally considered to be an acceptable practice throughout Canada. In these situations, the bacteriological quality of irrigated effluents must be at least as stringent as criteria specified for primary contact recreation.

Disinfection of wastewater discharges prior to land application is not normally required when lagoons and/or holding ponds are designed into the spray irrigation system (see Section 2.2.1). Only where public health risk is a concern, such as in parks or golf courses, is the practice considered.

Table 7 summarizes the existing Canadian guidelines for irrigation of agricultural and recreational lands.

2.3.3 Subsurface Land Disposal. Subsurface land disposal of liquid wastes can involve such systems as septic tank-tile fields, rapid infiltration ponds, landfills, and deep-well injection practices. In addition, the application of wastewater to land surfaces (irrigation) and the spreading of sludge onto land can result in the migration of contaminants into the soil column and eventually to the groundwater. Provincial guidelines/regulations on the design and operation of subsurface disposal practices have been prepared by various jurisdictions. These guidelines generally specify siting requirements, geological and hydrogeological surveys, systems layout, distances of site boundaries to watercourses and wells, and monitoring and control requirements. The stipulation of bacteriological limits is not normally included in such guidelines.

The microbiological contamination of groundwater has been identified as the cause of outbreaks of waterborne disease in Canada and the United States (Keswick and Gerba, 1980). In the U.S. from 1946 to 1977, Craun (1979) reported that there were 264 outbreaks and 62 273 cases related to contaminated groundwater. Overflow from septic tanks and cesspools was responsible for 42% of the outbreaks, with 71% of the illnesses resulting from the use of untreated groundwater in non-municipal water supply systems.

A number of studies have been initiated concerning the detection of viruses in groundwater after wastewater application to land or direct groundwater recharge. Wellings et al (1975) demonstrated vertical and lateral movement of virus in a secondary effluent discharged to a wetland. Viruses were recovered from 3 m deep wells and were shown to have migrated 7-38 m laterally, surviving at least 28 days. At a spray irrigation site, viruses were recovered from groundwater after percolation through 3-6 m of sandy soil (Wellings et al, 1974). Vaughn and Landry (1977, 1978) and Vaughn et al (1978) reported isolations of viruses from four groundwater recharge sites, from a stormwater

TABLE 7 GUIDELINE SUMMARY FOR IRRIGATION OF AGRICULTURAL AND RECREATIONAL LANDS

Province	Agriculture	Recreation
British Columbia	Secondary treatment with disinfection (150 ft. buffer zone)	Secondary treatment, filtration, 60-day storage, with disinfection. or
	Secondary treatment, 60-day storage, with disinfection (no buffer zone)	Lagoons (winter storage), 60-day storage, with disinfection.
Alberta	Primary treatment plus storage (site dependent) or Lagoons (4 anaerobic) cells, followed by storage ponds for winter flow.	Secondary treatment, storage (site dependent), with disinfection as required.
Saskatchewan	Secondary treatment or Lagoons (two-cell facultative) with overall storage capacity of 280 days.	
Ontario	Secondary treatment or equivalent, with disinfection (effluent irrigation not allowed for crops for direct human consumption).	Secondary treatment followed by 2 ponds (30-day storage each), disinfection as required to maintain F.C. count of 14/100 mL. (0.5 mg/L F.R.C. (Free Residual Chlorine) after 30-minute contact).

recharge basin, and from groundwater under a sanitary landfill. In a study of viruses in groundwater under rapid infiltration lagoon cells, Schaub and Sorber (1977) reported that the groundwater contained viruses at depths of 29 m and lateral distances of 183 m, with viral concentrations of about 8.3% of the concentration of the applied effluent. Cooper et al (1974) recovered virus from leachate from both an open dump and a sanitary landfill.

The results of these studies, and others, demonstrate the potential for transport of pathogens for long distances through soils into groundwater. There are many factors such as the degree of soil saturation, subsurface flow, hydrogeologic structure, etc., involved in this movement. These factors should be investigated at sites where wastes are to be applied. However, judging from the previously cited statistics, accidental breakthrough of pathogens to groundwater does occur. The contamination of

groundwater by pathogens, and particularly viruses, requires further investigation. The results obtained from such studies would be helpful in planning and operating land disposal sites and septic tank-tile disposal fields.

2.4 Dechlorination of Municipal Effluents

Methods of reducing or eliminating residual chlorine levels in disinfected discharges include the addition of reducing chemicals, activated carbon contacting, and holding ponds.

Reducing chemicals include sulphur dioxide, sodium sulphite and sodium metabisulphite. Sulphur dioxide is the most commonly used agent, since supply and handling of the chemical is in a manner similar to chlorine. Reactions of sulphur dioxide with both free and combined residuals are nearly instantaneous, and are proposed as follows:

$$SO_2 + H_2O \rightarrow H_2SO_3 \quad (1)$$

$$HOCl + H_2SO_3 \rightarrow H_2SO_4 + HCl \quad (2)$$

$$NH_2Cl + H_2SO_3 + H_2O \rightarrow NH_4HSO_4 + HCl \quad (3)$$

$$NHCl_2 + 2H_2SO_3 + 2H_2O \rightarrow NH_4HSO_4 + H_2SO_4 + 2HCl \quad (4)$$

Based upon the above reaction equations, 1.8 mg/L SO_2 is required to dechlorinate 1 mg/L chlorine residual measured as mono-atomic chlorine molecule "Cl" (or 0.9 mg/L SO_2 for 1 mg/L Cl_2 gas since $Cl_2 + H_2O \rightarrow HOCl + HCl$). In those installations not large enough to warrant the use of sulphur dioxide in cylinders, either sodium sulphite or sodium metabisulphite can be used for dechlorination. This reaction requires 3.55 kg of pure sodium sulphite per kg of chlorine residual "as Cl" removed. Dechlorination of toxic chlorinated effluents with sulphur compounds is capable of preventing all chlorine-induced aquatic toxicity in wastewater effluents (Finlayson and Hansen, 1978; Ward et al, 1976; Martens and Servizi, 1975).

Total estimated annual cost (amortized capital plus operating expenses) for sulphur dioxide dechlorination at a 3.8×10^4 m^3 secondary sewage treatment plant is approximately $62 000 U.S. (Gan and Chen, 1978). Ho et al, (1980) estimated SO_2 dechlorination costs are approximately 32% to 62% of chlorination costs for secondary sewage treatment plants ranging in capacity from 455 to 45 460 m^3/day.

Granular activated carbon can be used to dechlorinate wastewaters but it is much more expensive (12 times) than the sulphur compounds (Gan and Chen, 1978).

However, the use of activated carbon can serve several functions in addition to the removal of chlorine residuals. Some removal of soluble organics is accomplished through absorption by the carbon, and dichloramine has been observed to decompose to nitrogen gas following contact with activated carbon (Howland and Wallace, 1980; White, 1978; Snoeyink and Suidan, 1975).

Prolonged storage, especially in the presence of sunlight, results in the gradual disappearance of residual chlorine and the formation of chloride. Information on the storage time required to dechlorinate wastewater is sketchy; periods of 6 hours or longer have been indicated as minimal time limits (White, 1978). Capital costs of holding ponds may be higher than chemical dechlorination systems, primarily because of land costs. However, because of their operational simplicity, use of holding ponds to dechlorinate effluents from small wastewater treatment plants with part-time operators, or operators with limited experience, may be advantageous. Total cost for a holding pond operation has been estimated at 1.5 cents/m^3 (Gan and Chen, 1978).

2.5 Alternatives to the Chlorine Disinfection Process

The adverse environmental effects of residual chlorine in chlorinated wastewaters have prompted a search for a substitute which would satisfy disinfection requirements and prove to be environmentally acceptable. Potential disinfection alternatives include ozonation, ultraviolet radiation, chlorine dioxide, bromine, and gamma radiation. Ozone and ultraviolet light appear to be the most promising options. As with chlorine, however, there are a number of questions about these alternate disinfectants that must be addressed, specifically:

1) What level of application is needed for effective disinfection?
2) What products are formed, at what rates and at what concentrations?
3) What is the impact of those compounds on human health and aquatic biota?
4) What level of pretreatment is required to make the disinfection process effective?

Ozone is a powerful oxidant that has been used for odor control and colour removal as well as for disinfection of potable water supplies for many years. In recent investigations with wastewater effluents (Meckes and Venosa, 1978; Venosa et al, 1978; Kay et al, 1977) ozone has proven to be an effective bactericide and virucide in tertiary

treated discharges. Disadvantages of ozone include the following: its effectiveness on lower quality effluents is questionable; control instrumentation appears to be expensive; and operational expertise is essential.

Ultraviolet radiation has a sterilizing effect on microorganisms. With wastewater, lethal action cannot be exerted through more than a few millimetres of the liquid because of the high absorbance of rays by the water and by interfering substances such as suspended solids. Considerable effort has been expended in attempts to perfect the proper UV irradiation equipment for wastewater disinfection. For example, the shallow penetration problem can be overcome with enhanced mixing within the UV disinfection unit. Ho and Bodin (1981) have successfully used a commercial UV disinfection unit (film thickness approximately 2.5 cm) to disinfect tertiary and secondary effluents. The cost for UV disinfection was claimed to be competitive to chlorination/dechlorination costs (Ho, 1981). Like ozone, UV radiation is quite sensitive to effluent quality variations, and equipment must be designed to accommodate fluctuations in flow volume and quality (Severin, 1980: Wolf et al, 1978; Johnson et al, 1978; Scheible et al, 1978; Oliver and Cosgrove, 1975).

Full-scale experience with ozone and ultraviolet disinfection is limited. In Canada, the use of these wastewater disinfection alternatives at municipal sewage treatment plants is nonexistent. Cost comparisons of disinfection alternatives have resulted in chlorination being the most economical option. However, these cost comparisons should no longer be used in isolation. All things are not equal between the various disinfection methods and one has to weigh the advantages and disadvantages of each option; cost is only one of many factors. The preferred disinfection method will be the one that:

i) gets the job done easily;
ii) is known to have a minimum health and safety risk;
iii) is easy to apply, measure and control, and
iv) is reliable.

2.6 Conclusions

1) Chlorinated municipal wastewater treatment plant discharges are but one source of residual chlorine loading to the environment. Other significant sources which may impact on the local environment include industries and power plants.

2) The elimination or reduction in the amount of municipal wastewater chlorination would reduce the potential for chlorine-induced toxicity in receiving waters but at the same time could increase public health risks.

3) Criteria which were used in the design of existing chlorination facilities may not be adequate to ensure effective pathogen kill. Upgrading techniques for chlorination facilities can be found in the literature.

4) The orthotolidine method of residual chlorine analysis is plagued by interferences and should be replaced with either the DPD test or the amperometric titration method of analysis.

5) Treatment plant operators require schooling in the importance of maintaining control over residual chlorine levels in their discharges.

6) At present, many chlorination control systems are poorly designed and operated at municipal sewage treatment plants.

7) Bacteriological loadings to surface waters occur as a result of discharges from a variety of sources on both a continuous and intermittent basis. The impact of any one discharge, its control and the effect of its control on the overall quality of the receiver, must be assessed taking other sources of contamination into consideration.

8) Pretreatment of sewage prior to disinfection has a positive impact on the efficiency of a disinfection process. Organic compounds and inorganic substances normally found in raw or partially treated sewage, may be removed by physical, chemical and biological pretreatment processes. An effluent is thereby produced that not only is more amenable to disinfection but also contains lower concentrations of organisms, nutrients, toxic substances and other compounds that could have a detrimental impact on a receiver.

9) Disinfection of primary treated effluents requires case-by-case evaluation in order to determine process effectiveness. It has been suggested that if bacterial target levels cannot be achieved by using less than 25 mg/L chlorine dosage, or having end-of-contact chlorine residuals of less than 2.5 mg/L, then a higher level of pretreatment and/or improvements to the disinfection process should be considered. Based on limited research in the area, it has been demonstrated that effluent with total coliform counts of 2 500/100 mL and fecal coliform levels of 200/100 mL can be consistently produced using current chlorination technology with nominal dosages and proper operating conditions. The Working Group considers the above levels

reasonable objectives for effective disinfection. Site details and specific water uses, however, will dictate effluent disinfection requirements.

10) Disinfected effluents from well-operated primary wastewater treatment plants with chemical addition for phosphorus removal, or from secondary biological or tertiary plants, should be capable of consistently achieving bacterial target levels.

11) Containment of liquid effluents in lagoon cells has been identified as effecting a 99.9% reduction of various viruses and bacteria in wastewater discharges. Storage times may be determined on the basis of bacterial reduction and receiving water quality requirements. Lagoon systems operating with one or two discharges per year will normally meet target levels for bacterial discharges.

12) Disinfection of lagoon effluents will normally be required in short retention (eg. 30 days) situations in order to achieve consistent bacterial reduction. Case-by-case evaluation of the effectiveness of the disinfection process will be required.

13) Prediction of the bacterial content of stormwater runoff and the correlation with pathogen concentrations is more difficult than for sanitary sewage. Although pathogens may be present in stormwater runoff, their presence is related to land use, climatogical characteristics and hydrologic behaviour.

14) In general, disinfection of land runoff does not appear to be a practical method of controlling bacterial discharges to receiving waters. More appropriate methods of control, such as stormwater holding ponds, may preclude the need for disinfection or at least enhance the effectiveness of the process.

15) Combined storm sewer discharges are a serious problem in many Canadian municipalities. Efforts to alleviate the problem include increasing the capacity of the combined sewer or constructing separate sewers. Disinfection of CSO discharges is not a practicable method of controlling bacterial discharges from this source.

16) Bacterial discharges from industrial sources such as food processing plants (eg. meat and poultry plants) and the pulp and paper industry have been found to have a significant impact on local water quality in receiving waters. The utility of disinfecting municipal effluent discharges to a surface body of water must be assessed in relation to the impact of nearby industrial discharges on that same body of water.

17) Microbiological criteria for surface waters vary from province to province and are categorized according to water use (Table 6).

18) Irrigation of agricultural or recreational land with treated wastewater is controlled by the provinces. Although empirical guidelines have been developed for land disposal applications under some jurisdictions (Table 7), the scientific basis for health-oriented stipulations must be further elucidated.

19) Microbiological contamination of groundwater has been identified as the cause of disease outbreaks in North America. Although provincial guidelines and regulations control the design and operation of subsurface waste disposal systems, a need for further research, principally in the area of viral transport through soils, has been identified.

20) Dechlorination of chlorinated effuents with sulphur compounds removes the possibility of acute chlorine-induced aquatic toxicity in wastewater effluents. Granular activated carbon and prolonged storage of chlorinated effluents are alternative methods for dechlorination, but may be more expensive to construct and/or operate.

21) Ozonation processes have been used in Canada principally for the disinfection of potable water. Although a proven bactericide and virucide, ozone's reduced effectiveness in lower quality effluents, the required control instrumentation, the necessary operational expertise and higher cost make it an unattractive alternative in smaller municipal plants (i.e. less than $4.554 \times 10^4 m^3$/day). At larger plants, ozone may be a viable alternative to chlorine.

22) Ultraviolet (UV) irradiation of municipal sewage is a promising disinfection alternative. The efficiency of UV irradiation is sensitive to effluent quality and therefore should be considered only for effluents that receive at least secondary treatment. In terms of cost, ultraviolet irradiation appears to be a possible alternative to a chlorination/dechlorination system for new treatment plants and some retrofits. However, further research is needed on the effects of UV irradiation on sewage, especially on the formation of toxic byproducts.

3. PUBLIC HEALTH PROTECTION AND THE APPLICATION OF MUNICIPAL WASTEWATER DISINFECTION

Previous discussion in this review centred on the existing effluent and water quality criteria that regulatory agencies have adopted. These criteria vary according to receiving water use and are founded on the principle of public health protection and the potential health risk associated with water use. The degree of protection actually being provided as a result of the disinfection of municipal wastewaters, or as a consequence of complying with bacteriological water quality limits is a question that is addressed in the following assessment of the need for chlorination of wastewater effluents. The ability of the natural environment to eliminate indicator bacteria and pathogens through self-purification processes is examined and the redundancy aspect of wastewater disinfection in some situations is explored.

The health implications associated with the formation of chlorinated organic compounds in chlorination processes is a concern that has been highlighted in recent discussions. The following chapter touches upon the problem of human and animal exposure to these chloro-organics and introduces areas where further research should be directed.

3.1 Indicator Organisms

The coliform group continues to be used by provincial environmental and public health agencies as an indicator of fecal contamination in receiving waters. However, various problems concerning the use of coliforms as indicators have been identified. These problems include variations in testing procedures used by laboratories, difficulties in predicting the presence and behaviour of coliforms in the environment and the questionable relationship between coliforms and pathogenic organisms in municipal discharges, non-municipal discharges and surface waters.

3.1.1 MPN vs MF Procedure. The advantages and disadvantages of the multiple-tube fermentation (MPN - most probable number) procedure and the membrane filter (MF) technique for assay of total coliforms and fecal coliforms in waters and wastewaters have been discussed extensively by Health and Welfare Canada (1978) and will only be briefly reviewed here. These two methods do not give strictly comparable results, although at low coliform levels the confidence limits of both the MPN and MF methods are large. The advantages of the MF technique over the MPN procedure include the rapidity of the test,

ease of testing, and the reduction of space, labour and equipment. With the use of portable equipment, the MF test procedure can be performed directly in the field. Correlation between the two procedures must be approached on a case-by-case basis.

3.1.2 Presence and Behaviour of Coliforms in the Environment. An understanding of the presence and behaviour of coliforms in the environment is an important element in any discussion on water quality criteria and public health risk. Coliforms do not necessarily originate in the intestines of warm-blooded animals, nor do they always come from man. In fact, some strains included in the total coliform group are not generally found in fecal material. Organisms of the Klebsiella, Enterobacter and Citrobacter genera have been found in soils and on vegetation but are infrequently isolated in the feces of normal individuals and then only in low numbers (Pipes, 1978; Health and Welfare Canada (HWC), 1978). The fecal coliform group is comprised principally of the genera Escherichia coli (E. coli) and to a lesser extent Klebsiella and Enterobacter. The presence of coliforms in surface waters is therefore not a positive indication of fecal contamination and a follow-up investigation (i.e. sanitary survey) is the only method of verifying the presence or absence of a fecal discharge in problem or questionable situations.

Various studies have been conducted which attempted to assess the behaviour of coliforms (i.e. die-off, reproduction) in receiving waters (Zanoni et al, 1978; Bellair et al, 1977; LaBelle et al, 1980; Mitchell and Morris, 1969). Availability of organic matter, and inorganic nutrients, the ambient pH, and the presence of extraneous materials such as disinfectants, heavy metals and other substances such as antibiotics in the receiving environment have been shown to affect the survival and growth potential of bacteria. In situ studies examining the die-off or disappearance of enteric bacteria have concentrated on two principle factors: dilution and temperature. Dilution is strictly a physical phenomenon, the impact of which can be calculated using effluent coliform densities, length and depth of the diffuser, the rate of discharge and receiver flow volume. Temperature affects the survival rate of bacteria, for as the temperature increases, survival decreases. Studies conducted in Lake Michigan (Scarce et al, 1964; Zanoni et al, 1978) and in a sub-Arctic Alaskan river (Gordon, 1972; Davenport et al, 1976) showed 90% bacterial reduction in about 380 minutes at a water temperature of 10°C versus 3.2 to 6.5% bacterial survival after seven days at 0°C. It was concluded in these studies that warmer temperatures stimulate antagonistic biological forces in the aquatic environment

and the proliferation of such natural predators of bacteria as protozoa. Although other factors such as sedimentation, adsorption, ultraviolet irradiation and natural die-off affect the disappearance of coliforms, the impact of temperature on the natural predator populations in both freshwater and marine waters may be the most significant factor in the reduction of bacterial levels (Mitchell, 1972; Smith and Gerard, 1981). It is possible, however, that regrowth of some enteric bacteria may occur in some warm, nutrient rich freshwaters.

The effect of chlorinated effluents on natural antagonistic biological forces has been cited as a contributing factor to the phenomenon known as bacterial regrowth (Berg et al, 1980; Shuval et al, 1973; Kinney et al, 1978). Bacteriological investigations performed on the Trinity River in Texas (Silvey et al, 1974) concluded that beneficial heterotrophs were more susceptible to chlorine than fecal or non-fecal coliforms, and thus regrowth of coliforms to densities of three and four times the levels at outfalls occurred due to the reduced level of natural competitors and predators. Work in Israel supported this conclusion (Shuval et al, 1973). While these two investigations were able to observe the regrowth phenomenon in the environment and others have observed bacterial regrowth in laboratory studies, Bell (1979) stated that enteric bacteria are not likely to proliferate to large densities in receiving water environments because of the temperature factor and its effect on regrowth. Bell pointed out that the exception to this behaviour has been observed in carbohydrate-rich waters, usually waters associated with pulp and paper wastes. Huntley et al (1976) presented evidence to suggest regrowth of coliforms near a pulp and paper mill in Mobile Bay, Alabama, where coliform numbers increased from 790 000 to a high of 4 900 800 and then dropped to 7900 at a distance from the outfall. This particular area was influenced by tidal cycles and the authors stated that there was a possibility of pollution from a distant sanitary sewer or from land runoff. Menon and Bedford (1972) showed an increase in coliforms from 1400 to 4400 in the Rainy River, Ontario, which was receiving pulp and paper and municipal waste effluents. They concluded that the increases could be due to regrowth, land runoff or the flow pattern of the river.

In summary, the existence and behaviour of indicator organisms in the environment is not easily predictable. The potential for multi-source and multi-quality inputs, the deficiencies of indicator organism specificity and the variability in bacterial survival rates in chlorinated and unchlorinated waters are major interferences that have a limiting effect on the establishment of the utility and need for wastewater disinfection.

3.1.3 Coliforms and Pathogens - Their Relationship. The relative numbers of coliforms, pathogenic bacteria, viruses and parasites in sewage and receiving surface waters are important considerations when evaluating public health risk and the validity of coliform standards. Several studies have attempted to correlate the numbers of indicator bacteria with the presence or absence of pathogenic bacteria. For the most part, however, actual ratios between average concentrations of indicators and of pathogens are inconsistent.

The inconsistencies associated with indicator/pathogen ratios are not unexpected because pathogen flora are not normal inhabitants in the bodies of human or warm-blooded animals. In assessing the relationship between indicator density and pathogen density, the following points must be considered (Pipes, 1978):

1) at any given time only a small percentage of the population may harbour and excrete pathogenic bacteria and viruses in their feces;
2) intestinal viral infection and virus excretion are transient phenomena;
3) the majority of those excreting pathogens in their feces may be subclinical cases;
4) fecal excretion of some viruses is subject to seasonal variation;
5) methodologies for identification and quantification of all pathogens are often poor or non-existent;
6) individuals may harbour and excrete more than one type of pathogen, and
7) there are many hundreds of potential pathogens.

Primary treatment of wastewater does not necessarily effect a reduction in numbers of bacteria; secondary treatment may remove in excess of 90% of the coliform population. Although simultaneous reduction of coliforms and pathogenic bacteria would be expected, such is not the case. Kenner and Clark (1974) discovered, while investigating the efficiency of secondary treatment, that although fecal coliform numbers were reduced by 96%, Pseudomonas aeruginosa and Salmonella decreased by only 40% to 50% and 7% to 10% respectively. Postchlorination of treated wastewaters has been identified by several authors to be an effective means of reducing Salmonella populations (EPS, 1978b; Brezenski et al, 1965), and populations of Klebsiella, E. coli and Enterobacter-Citrobacter (Kinney et al, 1978). Geldreich and Van Donsel (1970) found Salmonella to be more sensitive than indicator bacteria to chlorine; Schiemann et al (1978) had similar findings when disinfecting with ozone and chlorine dioxide. Kabler (1959) found that the resistance of E. coli and Pseudomonas aeruginosa to free chlorine at neutral pH values

was approximately the same but less than for S. typhosa and Shigella dysenteriae. Resistance to combined chlorine was comparable between those organisms but was considerably greater than that found for free chlorine. Survival in 0.3 mg/L of free chlorine was negligible, while under the same conditions the test organisms were able to completely survive contact with 0.3 mg/L combined chlorine.

In surface waters, the relationship between indicator bacteria and pathogenic bacteria has not been well defined. To ascertain whether there was any level of total and fecal coliform densities below which pathogenic bacteria could not be isolated, several in situ surface water studies have been conducted, (Gallagher and Spino, 1968; Smith and Twedt, 1971; Silvey et al, 1974). These studies indicated that the difficulty in establishing the natural relationships between indicators and pathogens in stream waters was tempered by factors such as seasonal pollution, the number of pathogen excreters among the human and animal populations within specific drainage basins and the pathogen selected for analysis. High fecal coliform levels have occurred in conjunction with low Salmonella densities and vice versa (Geldreich, 1970; Dutka and Bell, 1973; Smith et al, 1973).

The number of enteric viruses isolated from sewage samples is very much dependent upon the methodology used to recover the viruses, the time of day when sampling occurs, and the season of the year (IJC, 1980b; EPA, 1978; Gerba et al, 1975). Because of the variability, true comparison of the currently available sewage viral concentration data from one study area to another is not possible.

The amount of viruses present in wastewater effluents released to various bodies of water further depends on the efficiency of the sewage treatment and wastewater disinfection processes (Lothrop and Sproul, 1969; Malina, 1977; Malina and Sagik, 1974). Table 8 shows the amount of infective viruses that survive wastewater treatment and chlorination processes (Mahdy, 1979). Based on the estimation that wastewater can contain up to 10 000 PFU/L (EPA, 1978) the amount of residual virus in wastewater effluents may range from 9 PFU to 5000 PFU depending on the type of treatment. Different viruses vary widely in their sensitivity or resistance to disinfection with chlorine. Table 9 illustrates that in the same suspension, at the same pH and temperature, to inactivate 4 logs (99.99%) of Coxsackie virus A6 required contact with chlorine for a period 44 times longer than that required for Reovirus 1. Thus it is difficult to apply disinfection data based on one virus to other viruses even if they belong to the

TABLE 8 VIRUS REMOVAL IN WASTEWATER TREATMENT (SPROUL, 1977)

Treatment	Expected Removal (per cent)	Residual Virus† (PFU/L)
Primary		
Primary sedimentation	0	10 000
Chlorination	50	5 000
Secondary		
Trickling filters	50	5 000
Chlorination	50	2 500
Activated sludge	90	1 000
Chlorination	50	500
Tertiary		
Precipitation of phosphate and sedimentation	90	1 000
Activated carbon absorption	10	900
Chlorination	99	9

† Based on estimated 10 000 PFU/L influent.
PFU Plaque Forming Units

same group. On the other hand, chlorine contact of 120 minutes under the conditions specified inactivated 99.99% of the viruses listed in Table 9, but may not inactivate the same amount of other viruses.

Viruses will not replicate in a non-living medium or an unsusceptible host and thus are present in receiving surface waters in smaller numbers than bacteria. However, viruses discharged into the water environment (freshwater and seawater) survive longer than bacteria (Berg and Metcalf, 1978). Survival times depend mainly on the type of virus, the flow rate of water, the climatic conditions (especially temperature), the degree and type of pollution and whether the virus is free or solid-associated. As with bacterial pathogens, the microbial population in water and water temperature have a significant influence on virus survival. For example, Coxsackie virus A2 survived longer in distilled water, longer in river water previously autoclaved to destroy the microbial population (Clarke and Kabler, 1954; Geldreich, 1972) and longer in seawater previously heated for 1 hour at 45°C than in sewage (Geldreich, 1972). In other experiments using sterile distilled water, spring water, or well water to which 100 000 infective doses per litre were added either alone or with various bacteria at a density of 1000 cells per litre, virus survival was markedly reduced by the association with the bacteria. Table 10 illustrates the range of

TABLE 9 TIME REQUIRED FOR 99.99 PER CENT IN ACTIVATION OF VARIOUS HUMAN VIRUSES* WITH 0.5 mg/L FREE CHLORINE (LIU AND MCGOWAN, 1973)

Virus	Time (min.)
Reo 1	2.7
Reo 3	4.0
Reo 2	4.2
Adeno 3	< 4.3
Coxsackie B2	6.5
Coxsackie A9	6.8
Coxsackie B4	7.0
Echo 7	7.1
Echo 5	8.0
Coxsackie B1	8.5
Echo 9	12.0
Adeno 7A	12.5
Echo 8	13.0
Echo 11	14.0
Polio 1	16.0
Echo 24	20.0
Adeno 12	23.5
Echo 1	27.0
Polio 3	30.0
Coxsackie B3	35.0
Coxsackie A5	35.3
Coxsackie B5	39.5
Polio 2	40.0
Echo 12	> 60.0
Coxsackie A6	>120.0

* In samples of Potomac River water at 2°C and pH 7.8

stability of viruses that were suspended in waters with different degrees of domestic pollution at 20-25°C (Mahdy, 1979). Variations in the time required for inactivation of 3 logs (99.9%) of infectivity are apparent among different viruses and even among data for the same virus.

Studies have shown that the discharge of a disinfected wastewater effluent containing an acceptable number of indicator organisms and a prescribed total residual chlorine does not give a direct indication of the potential viral hazard associated with the effluent (Berg, 1978; Berg et al, 1978; Mitchell, 1972; and Marzouk et al, 1980).

In summary, from available information, it is evident that ratios of indicator densities to pathogen densities in sewage and surface waters and how they change is quite

TABLE 10 STABILITY* OF VIRUSES SUSPENDED IN DIFFERENT TYPES OF WATER AT 20-25°C (AKIN ET AL, 1971)

Type of Water	Virus	Time (days)†
Sea or estuarine	Polio 1	2-8
	Polio 2	5-8
	Polio 3	4-8
River	Echo 6	4-15
	Coxsackie B3	2-28
	Polio 1	3-20
	Echo 6	3-8
	Coxsackie B3	2-3
	Polio 1	3-6
	Polio (type unknown)	10-22
Impounded fresh	Echo (type unknown)	6-24

* Expressed as days required for 99.9 per cent loss of infectivity.
† Upper and lower limits of various reports.

tenuous. In the case of Salmonella, qualitative information about the presence or absence of the organism has been obtained, but quantitative techniques for estimation of densities are poor; for other pathogens both types of information are lacking. There is ample reason to believe that, in a quantitative sense, relationships between existing indicator organisms and pathogens do not exist.

3.2 Municipal Discharges and Public Health Risk

Evaluation of public health protection as it relates to the management of wastewater and associated pathogens requires knowledge of:

1) the presence of agents that cause disease;
2) the dose-response characteristics of the agents involved, (i.e. the concentration of the agent and the concentration required to produce disease), and
3) how the agent might come into contact with susceptible individuals.

3.2.1 Disease Agents in the Wastewater. Pathogenic bacteria that have the greatest health impacts and that have been identified in wastewater include members of the

genera Shigella, Salmonella, and Escherichia. Other bacteria of concern include Yersinia enterocolitica and Vibrio cholerae. Viruses and parasites are also recognized as being an important concern. Hepatitis is the virus of greatest concern although numerous other viruses have been reported or are present in wastewater. Parasites of significance include Giardia lamblia and Entamoeba histolytica.

There are six species of Shigella of which two, S. sonnei and S. flexneri are the most common. The majority of the reported cases of shigellosis in the United States are caused by S. sonnei (Craun, 1974). Shigellosis, also known as bacillary dysentery, is an intestinal disease limited to man and higher apes. It spreads rapidly under improper sanitary conditions and primarily from person to person. However, contaminated water has occasionally been reported as the initiating source. Campylobacter bacterium can cause Shigella - like illnesses. Two large potable water-borne outbreaks have been documented, one in Vermont (C.D.C., 1978) and the other in Sweden (Mentzing, 1981).

The genus Salmonella contains a large number of species that are pathogenic to man. S. typhi, the causative agent of typhoid fever, is peculiar to man and causes a severe enteric fever. Fortunately, the incidence of this disease in North America is quite low. In the United States the incidence of salmonellosis (nontyphoid) has been greater than that for typhoid fever. Salmonellosis can be caused by a large variety of species of Salmonella and is characterized by diarrhea, abdominal pain, and vomiting. Its predominant cause (29.4% of all cases) is due to S. typhimurium, the typical species isolated. In 1974, 59 deaths out of 21 980 total cases were reported in the U.S. (Centre for Disease Control (C.D.C.), 1976).

Since the mid-1940s when Escherichia coli was associated with diarrheal disease in nurseries, it has become increasingly clear that varieties of this bacteria known as enterotoxigenic E. coli, are involved in waterborne enteric disease (Sack, 1975). These pathogenic strains may produce mild to severe cholera-like symptoms in the small intestine and produce an endotoxin, or they may develop in the colon and penetrate the epithelial cells and produce shigellosis-like symptoms (Dupont et al, 1971). Enteropathogenic E. coli has been shown to be the cause of traveller's diarrhea (Gorbach et al, 1975) and waterborne epidemics of diarrhea, such as the occurrence in Crater Lake National Park, Oregon, in 1975 (C.D.C., 1975). The morbidity of this disease in the United States and Canada is unknown because of a lack of reporting.

Yersinia enterocolitica bacteria are the etiologic agents for the disease called yersiniosis, a gastrointestinal illness. Yersiniosis has been reported in Ontario only since

1972; however an increasing number of isolations have occurred since that time (Toma et al, 1972; Toma, 1973; and Ontario MOE, 1980b).

Vibrio cholerae, bacteria which produce an acute diarrhea, have virtually been eliminated from water in North America (HWC, 1978). Occasionally cases of cholera are reported but these are usually among travellers returning from epidemic areas (Canada Disease Weekly Report (CDWR), 1981a).

More than 100 strains of viruses may be present in the intestines of man and animals. The most important of these, from the standpoint of the severity of disease produced, is the agent of infectious hepatitis.

Before the successful vaccination campaign of the 1950s, the virus poliomyelitis would have been listed as an important disease. However, less than ten cases of poliomyelitis per 1 000 000 population were reported from 1973 to 1975.

The other viruses found in wastewater include members of the Coxsackie, the Echo, the Adeno, and Reovirus groups. These produce various diseases including aseptic meningitis, myocarditis, respiratory involvement, and gastrointestinal upset. Children of preschool age have the principal incidence of infection with transmission primarily by person-to-person contact. The role of water in the transmission of these agents is not clear at this time. (Lennette, 1976).

In North America, parasites commonly associated with waterborne disease are the amoeba, Entamoeba histolytica (Amoebic dysentery), and the flagellated protozoan, Giardia lamblia (giardiasis).

In amoebiasis, the amoeba infects the human colon causing erosion of the superficial mucous membranes. It may eventually invade the tissue with consequent ulceration. In certain severe cases, the parasite may metastasize to other body organs. The parasite has the ability to encyst and these cysts subsequently enter the environment in infected feces. When the encysted amoeba re-enters a susceptible host, usually in contaminated food or drink, it germinates in the gut and infects or reinfects.

Giardiasis is an intestinal disease produced by infection of the gut by the protozoan G. lamblia. The disease ranges from subclinical to severe maladsorption. The parasite produces cysts that are passed with feces and spread to other hosts through fecal contamination. In a number of instances it has been associated with drinking water contamination (Craun et al, 1976). By September 1981, there was a cummulative total of 2021 cases of giardiases reported in Canada for that year (CDWR, 1981b).

3.2.2 Dose-Response Characteristics of Disease Agents. Information on the concentrations of various agents which produce clinically recognizable diseases (human dose response) is available for Salmonella typhi, certain of the other salmonellae, and some strains of E. coli and Giardia lamblia. Bryan (1974) has compiled a dose response listing for a variety of infectious agents and a summarized version of his data is shown in Table 11.

TABLE 11 DOSE-RESPONSE FOR SELECTED ENTERIC MICROORGANISMS (Bryan, 1974)

Microorganism	No. per dose†
Shigella sp.	10^2-10^3
S. typhi	10^4-10^7
Salmonella sp. (not S. typhi)	10^6-10^9
E. coli	10^6-10^{10}
Vibrio cholerae	10^3-10^8
G. lamblia	10^1-10^6 (infection without illness)

† Needed to produce illness in 25 to 75% of persons taking dose.

As shown in Table 11, the dose-response relationship is organism specific. In the case of the bacterial diseases, it normally takes a considerable number of organisms to elicit a significant response in those challenged. The conditions under which dose-response relationships are developed are important as demonstrated by the parasitic disease giardiasis, where in one case no clinical infections were seen with total doses as high as a million cysts, and in another case a dose as low as ten cysts produced infection in 100% of those challenged.

Quantitative measurements of the minimum infectious dose of enteroviruses for humans have been conducted with attenuated strains of poliovirus (McLean, 1973; Plotkin and Katz, 1966). After feeding gelatin capsules containing graded doses of the SM strain of attenuated poliovirus-1 to adult human volunteers, 100% of the volunteers became infected by 200 or 20 plaque forming units (PFU), 67% by 2 PFU and none after ingestion of 0.2 PFU (McLean, 1973). Thus the 50% human infectious dose of SM poliovirus-1 was calculated to be 1 PFU in this study. In humans who have previously

ingested trivalent Sabin poliovirus vaccine, the minimum infective dose of attenuated poliovirus may be elevated substantially (McLean, 1973).

There appears to be much ambiguity in the results of studies relating to dose-response characteristics of disease agents. In many studies, as cited in Table 11, large doses of pathogens are deliberately used in order that an infection rate may be achieved. Though giving important results, these studies do not yield data which contribute to our knowledge of the effect of dosage on response. In other words, the definition of "minimal dose" is not established in these types of studies.

Another point to consider with respect to data on dose-response is the definition of response for a particular study and/or pathogen. Infection and disease are not synonymous and a dose that produces the former without necessarily producing the latter is still classified as the infective dose. Infection may be detected by demonstration of antibody response without recovery of the pathogen from the host.

Finally, susceptibility to most infections depends on many factors and variables. It is necessary to take into account such things as age and condition of the person being administered the dose when discussing the actual number of organisms causing an infection.

The determination of minimal infective dose for pathogens in the environment is an inexact science and as such correlations between the concentration of disease agent in the environment, minimal infective dosage levels and human disease are not possible to define.

3.2.3 Disease Agent Contact. How a disease agent might come into contact with susceptible individuals is a science in itself and therefore too broad a topic to be detailed in this review. However, from the wastewater disposal/reuse perspective it is obvious that potential routes of disease transmission must be examined to determine the likelihood and significance of possible human-pathogen contacts.

Examination of disease transmission routes in the environment gives an indication of the potential risk to public health.

3.2.3.1 Drinking water. Infectious diseases transmitted by drinking water are primarily those with an anal-oral route of transmission and are generally associated with the contamination of water by human feces (Pipes, 1978). Unfortunately, Canadian statistics on waterborne disease outbreaks associated with drinking waters are limited and therefore it is necessary to refer primarily to U.S. data. Since the mid 1950s, there has

been a noticeable increase in the overall number of waterborne disease outbreaks reported to the U.S. Center for Disease Control. This increase has been even greater in the period 1971 to the present. Whether the observed increase was due to improved reporting, the deterioration of water quality or a complacent attitude to sanitation is not clear. However, the etiology of waterborne diseases has changed in recent years. Almost half the outbreaks (47%) and cases (47%) reported from 1971 to 1974 were reported as acute gastroenteritis for which no etiological agent was found. In 1975 the trend continued; slightly more than 70% of the outbreaks and 90% of the cases of waterborne illnesses were characterized as acute gastroenteritis of unknown etiology. Starting in the late 1970s, three etiologic agents, Giardia lamblia, Yersinia enterocolitica and enteropathogenic E. coli, were increasingly identified as the causative agents for drinking water associated outbreaks. Undoubtedly, some of the earlier cases of gastroenteritis of unknown etiology were caused by these three agents (Pipes, 1978).

Infectious hepatitis, the second most common etiological agent for drinking water associated outbreaks of infectious disease, is the only viral disease for which sufficient epidemiological information exists to support a waterborne route of transmission. Moseley (1966) cited 50 published reports of infectious hepatitis from 1896 to 1965 which can be attributed to contaminated drinking water. Municipal potable water systems were held responsible for 19 of the 50 outbreaks. For both infectious hepatitis and shigellosis, grossly contaminated raw water coupled with inadequate water treatment practices have been the most important factors responsible for the outbreaks. In fact, inadequate water treatment practices and/or contaminated supplies were the cause of a majority of the outbreaks (65%) and cases (63%) of waterborne diseases during the period 1971 to 1974 (Pipes, 1978). Similar observations were reported in previous surveys of community water supplies (McCabe et al, 1970).

In Canada, an outbreak of typhoid occurred in Bouchette, Quebec, where 40 cases were reported as a result of drinking untreated contaminated Gatineau River water (Martineau and Breton, 1972). In Kingston, Ontario, 42 individuals including 24 children contacted typhoid from a contaminated well (Mathias et al, 1976).

In spite of the frequency with which the culturable viruses such as Polio, Coxsackie, Echo, etc. can be recovered from sewage and surface waters (Clarke et al, 1961, 1964; Kelly and Sanderson, 1960) there has been only one documented drinking water associated outbreak of disease attributed to these agents (Craun and McCabe, 1973).

It is generally assumed that adequately treated and delivered drinking water should not contain any pathogenic microorganisms. As a practical objective, this is probably unattainable. A more realistic expectation is that, even under epidemic conditions of illness in the population whose sewage may contaminate the raw water source, the combination of natural purification and man-mediated treatment and disinfection will be such that outbreaks of waterborne infectious disease will occur very rarely, if at all—and that the probability of sporadic cases of infectious disease will be acceptably small. This objective has not been reached, as outlined earlier. The deficiency has its origin either in inherent defects in the microbiological indicator used or, as suggested by McCabe et al, (1970), in poor microbiological monitoring, particularly of private and semi-public systems.

While the use of the coliform group as an indicator has apparently been successful in controlling the major reportable contagious diseases, there is the question concerning diseases that are normally not reported and their possible relationship to drinking water quality. In the case of drinking water, the prime requisites of a bacterial indicator would be: i) consistent densities in raw water such that, if disinfection were inadequate, the indicator could be detected in some reasonable quantity of treated water; and ii) resistance to chlorination at least approaching that of the most resistant infectious agent potentially present. At this time, it is known that the coliform group of bacteria is less resistant to chlorination than some pathogenic organisms although these differences are believed to become negligible if a free chlorine residual is maintained. Chlorination will not destroy Giardia lamblia and other parasitic cysts - filtration is required before the water is fit to drink.

In summary, a study would be appropriate to determine if non-reported diseases are a problem in this country. If they are a problem, a second project should be initiated to find a substitute indicator resistant to chlorine. The study should also address the problem of the best strategy using disinfectant residual and the indicator system for producing the safest raw water as potable water source. It is also important to stress that until such a definite research project is done with positive results, the current use of the coliform group of bacteria should be continued. Finally, it is suggested that a workable national reporting system on waterborne disease outbreaks be developed in Canada.

3.2.3.2 Recreational waters. The most commonly reported infections associated with primary contact recreation are those of the skin, eyes, ears and upper respiratory tract.

Therefore, recreational water quality indicators ideally are microorganisms or chemicals whose densities in water can be quantitatively related to those potential health hazards resulting from recreational use, particularly those from activities which expose the upper body orifices to the water.

Otitis externa caused by Pseudomonas aeruginosa remains one of the most common swimming associated illnesses reported. Hoadley and Knight (1975) noted that the earache rate among swimmers was about 7.3% and that for nonswimmers 3.1% in their study group. They were able to recover P. aeruginosa from the auditory canals of more than 3/4 of the swimmers and about 1/3 of the nonswimmers with otitis externa. However, there were no definitive data showing whether the source of the organisms was the water or the auditory canals of the bathers themselves.

There have been about 300 cases of Mycobacterium balnei (Cleere, 1960; Farrington et al, 1960) and about a dozen cases of Aeromonas hydrophila (Hanson et al, 1977; Rosenthal et al, 1974) infections of wounds and abrasions obtained in the course of swimming. The former were associated with swimming in warm, mineral water pools, and the latter in ponds and lakes.

One of the most commonly reported skin diseases associated with swimming is swimmer's itch (Osment, 1976) caused by the cercariae of a bird schistosome.

It has long been recognized that swimming in small ponds and streams recently contaminated with the urinary wastes of cattle carries with it the risk of leptospirosis (Nelson et al, 1973; Diesch and McCulloch, 1966). Of some 119 cases of leptospirosis reported to the U.S. National Center for Disease Control in 1975 (CDC, 1977a), 36 (29%) were probably due to such circumstances. In 1976, there was an outbreak of 7 cases in Tennessee in which all the individuals had a history of swimming in a particular creek within a month preceding their illness (CDC, 1977b).

There has been one outbreak of hepatitis associated with recreational waters (Bryan, 1974); however, drinking rather than swimming was the more likely route of transmission. It is of interest that there have been no reported cases of swimming associated outbreaks of poliomyelitis. Single outbreaks of Coxsackie A and Coxsackie B virus infections have been associated with swimming in natural bodies of water (Denis et al, 1974).

The most extensive, definitive and best documented outbreak of enteric disease associated with swimming in natural waters in the United States, and probably the entire world, was one in which 31 of 45 cases of bacillary dysentery caused by Shigella

sonnei were clearly traced to swimming in a five-mile portion of the Mississippi River below Dubuque, Iowa (Rosenberg et al, 1976). The attack rate among swimmers who took water into their mouths was 18%, and the fecal coliform density of the river water in the area as determined sometime after the peak of the outbreak was 17 500 per 100 mL. The Shigella sonnei isolates from both the infected individuals and the water had the same antibiogram. Furthermore, the incidence of shigellosis in Dubuque had been increasing during the 3-4 years prior to the outbreak.

Cabelli and his coworkers (1975a, 1975b, 1976b) compared the rates of gastrointestinal, respiratory, and other symptoms among swimmers and beach-going nonswimmers at "barely acceptable" and "relatively unpolluted" beaches over several years. In each of the first two years of the study, they found that the rate of gastrointestinal symptoms (vomiting, diarrhea, nausea or stomachache) was higher for swimmers at the barely acceptable beach than at the relatively unpolluted beach. They found that these differences could be ascribed to that portion of the population ten years of age and under. This finding was both expected and consistent with Stevenson's results (1953). Moreover, when the symptomatology rates were examined in relationship to the densities of a number of microbial indicators measured at the time of swimming, correlations were obtained between the swimming associated rate of gastrointestinal symptoms and the mean indicator densities for E. coli and enterococci in the bathing water. The swimming-associated gastrointestinal symptom rate (ie. difference between swimmers and non-swimmers) was between 3 and 4% and correlated with about 200 E. coli per 100 ml. The rate for relatively important gastrointestinal symptoms (those requiring the individual to remain home or remain in bed) was between 0.5 and 1%.

As seen from case reports and prospective epidemiological studies, swimming per se carries with it a certain risk of infections and irritations of the skin, ears, nose and upper respiratory tract. In addition, an increased risk of gastrointestinal infections, as well as infections of the skin, eyes, ears and upper respiratory tract occur, which is related to the microbiological quality of the water. Risk of contracting gastroenteritis is greatest among children who swim, and is correlated with E. Coli and enterococcus densities in the water, both indicators of fecal pollution. In spite of this relationship, it remains exceedingly difficult to prove a direct causative relationship between pollution by municipal waste discharges and disease outbreaks in bathers, except in instances of major contamination.

Currently, provincial regulations limit the choice of bacterial indicators, specify frequency and conditions of sample collection and give little latitude in the interpretation of the data. It would seem, however, based upon previous discussion that interpretation of monitoring data is necessary, particularly with respect to the source of pollution (e.g., human vs. lower animal wastes, treated vs. untreated sewage, municipal vs. industrial effluents, household wastes vs. stormwater run-off), and the potential presence of pathogens. Data must be obtained on the health effects of indicator levels and pathogen densities in recreational waters. It should be employed in three ways: (i) to classify beaches against existing guidelines and standards; (ii) to evaluate pollution abatement activities and establish long-range trends and background data with regard to the quality of the waters potentially affected, and (iii) to establish the source and conditions of waterborne outbreaks of infectious disease.

Measurements for a number of indicators and even some pathogens are desirable in order to establish the proximity, nature, and importance of the sources of pollution of coliform biotypes (Knittel, 1975; Dufour and Cabelli, 1975) or streptococcal species (Medrek and Barnes, 1962; Geldreich and Kenner, 1969). As examples, the relative densities of E. coli, enterococci, Clostridium perfringens and bifidobacteria could provide some of this information. The levels of P. aeruginosa (Levin and Cabelli, 1972; Cabelli et al, 1976a) and A. hydrophila (Cabelli et al, 1975) also may provide useful information. High densities of Klebsiella in the absence of E. coli would suggest certain industrial sources (Dufour and Cabelli, 1976; Bauer, 1972). The ability to make these distinctions with respect to sources of contamination would be a valuable tool to both environmental and public health agencies.

3.2.3.3 Shellfish waters. Since 1900, typhoid fever, gastroenteritis of unknown etiology and infectious hepatitis have accounted for over 90% of the shellfish related disease outbreaks (Verber, 1972). Obviously, then, the major concern for shellfish contamination is the fecal wastes of man, and to a lesser extent, other warm-blooded animals. The etiological agent of one of the earliest and one of the latest outbreaks was Vibrio cholerae. In addition, three water-borne organisms, Vibrio parahemolyticus, Clostridium botulinum, and certain species of dinoflagellates, have been responsible for shellfish-borne outbreaks of infection or biointoxication. The association of these agents to man-made pollution is vague. Indicator bacteria representative of human fecal wastes will not predict the potential risks of these less frequent diseases (Pipes, 1978).

Even if all the recent outbreaks of shellfish associated infectious hepatitis and nonspecific gastroenteritis were attributed to shellfish illegally harvested from polluted waters, their occurrence must be reconciled with the absence of typhoid fever outbreaks since 1954 (Cabelli, 1978). A decrease in the number of typhoid cases and carriers in the population in combination with the relatively higher infective dose for S. typhosa would be one explanation. Another possibility is that, for a number of reasons including the relative survival properties of the two pathogens, standards (and possibly the indicator system) designed to prevent shellfish-borne typhoid fever are not adequate for effective control of infectious hepatitis and nonspecific gastroenteritis.

The need for controlled epidemiological-microbiological investigations to develop health effects criteria for shellfish-growing waters is obvious. Although the incidence of disease caused by Vibrio parahemolyticus and Clostridium botulinum is minor to date, research should be directed towards finding a simple method that will predict the risk of infection through shellfish by these organisms.

3.2.3.4 Agriculture/Irrigation Waters. Land application of wastewater is practised as a disposal system and/or a treatment system. This system may be used to provide supplemental irrigation water and nutrients or may be used primarily as an alternative method of final wastewater disposal. Effluent irrigation may be accomplished by means of a variety of spraying techniques, by the ridge and furrow method or by the overland flow or flooding method.

The disposal of wastewater on land provides many potential benefits but also carries risks not normally associated with standard irrigation practices. These risks include the general exposure of the local population, livestock and wildlife and ground and surface waters to microbiological, heavy metal and organic contaminants. Microbiological contamination is a particular concern in irrigation projects because of the concentration and variety of pathogens that may be present in domestic wastewater.

Wastewater effluents applied by sprinklers will produce extremely small mist droplets, called aerosols, which are easily transported by wind currents. It has been estimated that approximately 0.1% of the liquid is aerosolized during sprinkler irrigation of wastewater (Jurinak and Santillan-Medrano, 1974). Aerosols generated in connection with inadequately disinfected wastewater contain active bacteria and viruses. Humans may be infected by biological aerosols directly by inhaling the aerosol or indirectly by contacting material on which the airborne droplets have settled, such as clothing (EPS,

1977). Factors such as increased wind velocity, increased relative humidity, lower temperature and darkness are favourable toward the viability and travel of bacterial aerosols (Sorber and Guter, 1975; EPA, 1977).

Control measures that may be used to minimize potential health risks from aerosols include the practising of adequate disinfection, the maintenance of adequate buffer zones, the use of sprinklers that spray horizontally or downward with low nozzle pressure, the elimination of sprinkling during high winds and sprinkling only during daylight hours (EPA, 1976; EPA, 1977).

In addition to aerosols, pathogens concentrated in the upper layers of the soil column may be transported to nearby non-irrigated crops or directly to humans by flying insects or wind-borne dust. A dust-borne epidemic of Salmonellosis in Israel gives credence to this potential hazard (Foster and Engelbrecht, 1973).

At the turn of the century, cases of typhoid fever attributed to the eating of raw vegetables grown on soil fertilized with untreated wastewater led to extensive studies on the survival of enteric bacteria on such crops (Sepp, 1971). As a result, standards were developed regulating the use of wastewater effluents for irrigation (see Section 2.3.2). Today, the incidence of reportable diseases from this source is almost zero. The only recently documented case of disease outbreak involving irrigated food was a 1970 cholera outbreak in Israel which was attributed to the practice of irrigating vegetable crops with untreated wastewater (Cohen et al, 1971).

The risk posed to livestock that eat plant material from land irrigated with wastewater effluent is not well defined. These risks include those to humans via zoonotic organisms (i.e. transmissable between animals and man) and those to animals from human and animal pathogens that may be present in the wastewater effluent. Pathogens of concern include the bacteria Salmonella, Mycobacteria, Brucella, Esherichia coli, Bacillus anthracis and Leptospira, the reovirus and rotavirus groups and the helminth parasite Teania saginata (Yeager, 1980; EPA, 1977). The organisms of greatest potential risk are the Salmonella, the rotaviruses and T. saginata, as they are zoonotic and may be transmitted to man via contaminated meat or milk form infected livestock.

It has been suggested that, in the case of spray irrigation, termination of wastewater effluent application on pasture at least two weeks prior to pasturing or harvesting will minimize the microbiological risk to livestock (EPA, 1977; National Academy of Science, 1972). Parsons et al (1975) found that there was litte health hazard to cattle fed hay that had been irrigated with sewage effluent, baled when dry and cured

for fourteen days, and no health hazard to humans consuming meat from animals fed on this fodder.

The contamination of surface waters may be avoided through proper design of the irrigation system so that direct runoff is prevented (Sorber and Guter, 1975). Problems relating to ground water contamination through the surface or subsurface land application of wastewater has been discussed in Section 2.3.3. For additional information, EPA (1977) may be consulted.

The presence of organic contaminants in irrigation waters is a matter of considerable concern, partly because of the lack of sufficient research and study, and partly because many of these contaminants are toxic and potentially carcinogenic, teratogenic or mutagenic to humans. As soil seems to possess the ability to attenuate the input of toxic chemicals and metals through various mechanisms, it is essential that the fate of such chemicals during land irrigation not be overlooked.

In conclusion, it is evident that land disposal of wastewater does not represent a major mode of disease transmission in Canada. However, the fact that the practice of effluent irrigation is increasing in popularity as a wastewater disposal alternative gives cause for concern. The development of specific microbiological, organic and metals criteria should be pursued through research and monitoring studies.

3.3 R-Factors

Resistance (R) factors are extrachromosomal nucleic acid elements which are rapidly transferable among Enterobacteriaceae and many other bacteria by conjugation (Grabow et al, 1978). These plasmids may consist of up to 100 genes which may confer on the host organism resistance to a wide spectrum of antimicrobial agents as well as abnormal physiological, structural and morphological properties. R-factors are particularly known for their role in bacterial resistance to antimicrobial drugs which limits the efficiency of chemotherapeutic treatment of many diseases. Studies on the incidence of bacteria carrying R-factors (R^+ bacteria) in wastewater and polluted water resources indicate that water may be an important media for the spread of R^+ organisms (Shaw and Cabelli, 1980; Grabow et al, 1975; Grabow et al, 1974). Bell et al (1980) determined that coliforms, fecal coliforms and Salmonella that were isolated from the Red River, Manitoba, demonstrated a resistance to one or more of 12 antibiotics tested.

Since the R-factors concerned may, in addition to drug resistance, code for properties such as enterotoxin production which turns a normally harmless organism such

as E. coli into a severe pathogen, then the role of water in the spread of R^+ bacteria has public health implications which cannot be ignored. Some R-factors increase resistance to agents such as ultraviolet light, heavy metals, certain disinfectants or bacteriophages (Grabow et al, 1975). This is accomplished by modifying repair mechanisms, reducing permeability of the cell wall or cytoplasmic membrane, or by inducing enzymes which degrade compounds which are normally harmful to the bacteria. Such R-factors may increase the resistance of pathogenic bacteria to water purification processes and thereby contribute to health hazards. Careful evaluation of these and many other properties of R-factors indicate that the genetic flexibility of micro-organisms should receive special attention in considerations regarding water management and water quality standards.

3.4 Chloro-organic Compounds in Wastewater and Health Protection

The formation of chlorinated organic compounds in water and wastewater disinfection processes has been the subject of numerous laboratory and field investigations in recent years. A brief review of the chemistry of chlorination and the implications on the generation of chlorinated organic compounds is warranted.

Chlorination proceeds via a number of reactions involving organic compounds. The nature and concentrations of the reactive chlorine-containing species are of primary importance in determining the formation and yield of chlorinated organic compounds. For example, the potential chlorinating ability of hypochlorous acid (HOCl) has been estimated to be more effective than monochloramine (NH_2Cl) by about four orders of magnitude (Lee 1967; Morris, 1967). The chemical reactions between HOCl and organic constituents have been studied extensively under three general categories:

a) oxidation;
b) substitution, and
c) addition.

The predominant mode of action between HOCl and organic compounds in aqueous media is probably oxidation (Pierce, 1978). Although compounds undergoing oxidation will contribute to the overall chlorine demand of water, they probably do not yield organic derivatives as final products. In the majority of cases, no substitution or addition of chlorine into the organic molecule occurs; instead, the major pathway for the consumption of chlorine is believed to be reduction to yield the chloride ion (Pierce,

1978). Tests have shown that approximately 99% of the chlorination yield of secondary sewage effluents is in the form of chloride ion (Jolley, 1975).

Substitution reactions may be divided into two groups:

a) those resulting in formation of N-chlorinated compounds;
b) those resulting in formation of C-chlorinated compounds.

The formation of N-chlorinated compounds has been reported by several researchers. Numerous amides, amino acids, indoles, pyridine derivatives, purine derivatives and pyrimidine derivatives have been identified in sewage effluents (Jolley et al, 1978a). The chemical reactivity of organic amines toward electrophilic attack also occurs with inorganic nitrogen compounds such as ammonia to produce chloramines (i.e. combined available chlorine residuals). Amines may be expected to react much faster than amides to form N-chloro-derivatives (Morris, 1967). It has been demonstrated that NH_2Cl can react directly with nitrogenous organic compounds to form N-chlorinated species (Isaac and Morris, 1980). At chloramine and organic nitrogen concentrations normally found in wastewater effluents and in receiving waters in the vicinity of an outfall, formation of N-chlorinated compounds may proceed by direct reaction between NH_2Cl and the N-substrate. At reactant concentrations representative of freshwater, both NH_2Cl hydrolysis and direct interaction may be important in the transfer of Cl^- to nitrogenous organic compounds. The formation of the N-chlorinated species can affect both the disinfecting and toxic properties of the chlorinated water (Isaac and Morris, 1980).

Substitution of chlorine into organic compounds to form C-chlorinated derivatives has been summarized by Jolley (1973). These reactions can either be conventional substitution; i.e. substitution into aromatic or heterocyclic compounds, or of the haloform reaction type (IJC, 1980a). The latter reaction has been studied in detail in recent years in the chlorination of wastewater (Glaze and Henderson, 1975), as well as potable water (Rook, 1974; 1976) and cooling water (Jolley et al, 1978). The major precursors of the haloform reaction are considered to be m-dihydroxy aromatic compounds - common building blocks of humic materials and low molecular weight methyl ketones (Stevens et al, 1978). Another report on the possible formation of polychlorinated biphenyls indicates that the formation of PCBs via the substitution of chlorine into biphenyl present in wastes is not likely to be significant (Bonner et al, 1979).

The last generic type of organic reaction, addition, may occur with organic compounds containing reactive double bonds. For example, unsaturated fatty acids in

sewage effluents and natural waters may react with chlorine to produce chlorohydrin and dichloro compounds (Jolley et al, 1978). Additions of this nature are considered to be too slow to be significant in dilute aqueous chlorination reactions unless the double bond in the alkene is in close proximity to substituent groups capable of activating the site of unsaturation (Pierce, 1978).

It is evident from these various investigations that the potential exists for chlorinated organic compound formation during wastewater chlorination. Jolley et al, (1978) estimated that the chlorination reaction yields of chlorinated organic compounds in sewage effluents was 0.5 to 1%. However, very little is known concerning the environmental and public health significance of these compounds in receiving waters. It is well established that hydrophobic chlorinated compounds tend to biomagnify along the food chain; it is not known whether the compounds remain in solution, are adsorbed onto sediments or suspended particulates, or decay. Recent reviews (MacLure and MacMahon, 1980; Pike, 1980; Wilkins et al, 1979) indicate that existing data does not provide any conclusive evidence that low level exposure to halocarbons in water represents a significant health hazard. Experimental work on the environmental hazards associated with chloro-organics in disinfected municipal wastewaters is discussed in Chapter 5.

To put into perspective some of the concerns over quantities and characteristics of the chlorinated organics being generated in wastewater disinfection processes, other generative sources must be considered. Chlorine plays a central role in the disinfection of potable water. In turn, human exposure to chlorinated organics via water consumption appears to be dominated by trihalomethanes (THM's) (and $CHCl_3$ in particular) both in terms of quantity and widespread occurrence (Rook, 1974; Bellar et al, 1974). Within industry, the pulp and paper, food processing and organic chemicals industries are believed to be major producers of chlorinated organic compounds. Estimates have been made that between 500 and 10 000 tonnes per year of chlorinated organics are discharged from Canadian industries into the Great Lakes, with the major fraction arising from wood pulp processing in the paper industry (IJC, 1980a). Comparing these estimates with the 16.5 tonnes of chlorinated organic compounds estimated for sewage treatment plant discharges, (IJC, 1980a), wastewater disinfection processes appear to be insignificant contributors of chlorinated compounds in the case of the Great Lakes. The food industry uses chlorine in the form of chlorine gas or chlorine dioxide as a bleaching and maturing agent in wheat flours, in the canning, dehydration and freezing of foods and as a sanitizer/sterilizer in the cleanup of equipment, transport of product, etc. (Kirk and Mitchell, 1980).

Thus, it must be recognized in general terms that human and environmental exposure to chlorinated organics via potable water and food products and industrial discharges appears to be far more significant than via wastewater disinfection processes. However, any process/practice that has the potential for increasing loadings of toxic chemicals to the environment should be critically reviewed to seek alternatives for reducing or eliminating such discharges. This can only be accomplished through the development of refined data collection systems and analytical techniques based on sound epidemiological study designs.

3.5 Conclusions

1) The application of total and fecal coliforms as indicators of fecal contamination in surface waters is subject to misuse and misinterpretation. Coliforms are an ecologically heterogenous group of microorganisms, only some of which are consistently and exclusively associated with the fecal wastes of warm-blooded animals. Fecal coliforms, although a more feces-specific indicator than total coliforms, are composed mainly of E. coli and Klebsiella spicatum. Klebsiella sp. cannot be consistently recovered from human feces and have been found on vegetation, soils and in industrial effluents. Consequently, sanitary surveys may be necessary in order to identify the source of bacteriological contamination of surface waters.

2) Survival rates of coliform bacteria in surface waters are a function of several site-specific parameters (i.e. pH, metal ion toxicity, availability of nutrients, sunlight exposure, dissolved oxygen, competition, predation). The temperature of the receiving water appears to play a significant role in the survival and replication of bacteria. As ambient water temperatures increase, bacterial survival rates decrease in duration.

3) The discharge of residual chlorine in municipal wastewater effluents may have a detrimental effect on the natural bactericidal properties of receiving waters by killing scavenger organisms. Reactivation and replication of bacterial indicators and pathogens can result, especially in carbohydrate-rich waters.

4) While chlorination of wastewater discharges has been shown to eliminate/reduce concentrations of indicator bacteria and some pathogens (eg. Salmonella), other pathogenic bacteria and viruses have been identified as being less sensitive to chlorine and more resistant in the receiving environment than indicator organisms.

5) It is not possible to use the measurement of indicator density to determine the level of pathogen densities in wastewater effluents or surface waters with reasonable accuracy. Order of magnitude correlations of pathogen and indicator organisms have been established for some organisms from epidemiological data. There is ample reason to believe that, in a quantitative sense, relationships between indicator organisms and pathogens do not exist.

6) Although there are recognized inadequacies with the use of existing indicator organisms, they have served to reduce the incidence of disease and infection occurring via the potable water route for a number of years. Until other proven methods of detecting pathogens are available, the use of indicator organisms must continue.

7) Pathogenic bacteria that have the greatest health impacts and that have been identified in wastewater include members of the genera Shigella, Salmonella and Escherichia. Several viruses and parasites are also recognized as being an important public health concern.

8) Infectious dosages of pathogenic bacteria vary from one organism to another and from individual to individual. Infectious dose data (Table 11) are available for some, but not all, enteric pathogens; little or no data are available on "minimum dose" relationships.

9) Aside from the quantitative measurements of the minimum infectious dose of attenuated strains of poliovirus, very little information is available on viruses and their infectious capacities.

10) Until questions concerning the behaviour of indicators and pathogens in the environment are resolved, the infectious dose data for waterborne pathogens are of little use in interpreting water quality criteria.

11) Official Canadian statistics on waterborne disease outbreaks are limited. A workable reporting system on disease outbreaks is needed.

12) While the use of the coliform group as an indicator has apparently been successful in controlling the major reportable contagious diseases, the question exists concerning diseases not reported and their relationship to drinking water quality.

13) The most commonly reported swimming associated infections are those of the skin, ears and upper respiratory tract. However, it is difficult at this stage to correlate existing microbiological indicator densities with incidents of such infections.

14) While there is an abundance of data confirming the existence of pathogenic micro-organisms in treated effluents, there is a lack of direct causal evidence linking municipal waste discharges to disease outbreaks except under conditions of heavy contamination with human wastes or during epidemic conditions. Recent epidemiological information indicates that there is a risk of contacting gastroenteritis in moderately polluted waters (i.e. 200 E. coli/100 mL).

15) The basic limitations of indicator bacteria need to be recognized and appropriate measures taken to upgrade techniques for assessing the health hazards associated with recreational waters. Consideration must be given to the source of pollution, the distinction between sources, the temporal variability in pollution levels, and the general health of the community. Measurements for a number of indicators, and even some pathogens, are desirable in order to establish the proximity, nature and importance of the sources of pollution to a given area.

16) Land disposal of wastewater does not appear to play a major role in disease transmission in Canada. However, the potential for the spread of disease through crops, surface runoff and groundwater, does exist.

17) Additional research is necessary before a more meaningful guideline on bacterial water quality standards can be established. In the interim, existing guidelines should be used for the land application of wastewaters.

18) Although some provincial guidelines detail siting requirements, wastewater application rates and land use, most of the concern has been directed to microbiological and metal loadings. Little research has been conducted on the effects of organic contaminants on irrigated lands and crops and the resulting impact on man and food animals.

19) Evaluation of resistance factors of micro-organisms in water purification processes, wastewater treatment processes and their behaviour in the natural environment should be undertaken.

20) Chlorination reaction yields of chlorinated organic compounds in secondary sewage effluents can be as much as 1% of the applied chlorine dosage. Existing evidence is inconclusive with respect to wastewater disinfection and the associated reactions which produce chlorinated organic compounds and the threat to human health. Further evaluation in the form of epidemiological studies is needed to assess the health risk of organic chemicals in water supply systems.

4. WASTEWATER DISINFECTION AND ENVIRONMENTAL IMPACT

Chlorine is very effective as a disinfectant, antifouling agent and biocide. Its action, however, is not specific to target pest organisms and it may have adverse impacts on public and environmental health particularly when released as a chlorinated effluent into receiving water bodies. Substantial concern over these potential impacts has stimulated extensive research into questions concerning:

1) minimum levels of chlorine required for efficient disinfection;
2) analytical procedures used to measure chlorine at low concentrations;
3) chemical interactions of chlorine with materials in natural and waste waters;
4) toxicity of resultant products, and
5) the availability of disinfection alternatives.

In a broad sense, two main categories of chlorine-containing reaction products may be found as a result of wastewater chlorination:

1) residual chlorine, those chlorine compounds which possess an oxidative capacity, and
2) organo-chlorine compounds, formed by the reaction between oxidative chlorine compounds and organic compounds.

Throughout this section, the terms total residual chlorine (TRC) and total residual oxidant (TRO) are used without distinguishing between free residuals and the various combined chlorine and halogen residuals. While evidence suggests that differences in toxicity exist between chlorine species, the evidence has been contradictory from study to study because of variations in methods of detection, pH, temperature, salinity, concentrations of ammonia, etc. Thus, differentiation between the proportion of free and combined residuals at any one site has not been attempted and only total residuals are reported.

While extensive literature exists on the biological effects of residual chlorine, relatively little information is available on the biological effects of organo-chlorine compounds formed during chlorination. This section examines the effect that chlorine and the products of a chlorination process can have on fish and other organisms in the aquatic environment.

4.1 Toxicity in the Aquatic Environment

4.1.1 Freshwater and Marine Toxicity Levels. The literature is replete with information on the effects of chlorine on fish and other freshwater and marine organisms. (A review by Servizi (1979) is one of the more recent summaries on the impact of chlorine residuals on aquatic life and much of the information in this section is credited to Dr. Servizi). However, there are only a few reported cases of major fish kills occurring as a result of the practice of wastewater chlorination at municipal wastewater treatment plants throughout the United States, and no reports have been made in Canada. This lack of fish kill reporting in Canada cannot be taken to mean that fish kills do not occur or that habitat has not been alienated by residual chlorine discharges (Chamut, 1981). In the absence of field information on fish kills, it is possible that numerous other effects, effects that are of biological concern, are occurring.

Residual chlorine in the effluent from municipal wastewater treatment plants has been cited as the cause of major fish kills in Sacramento, California and the James River, Virginia, (Collins and Deaner, 1973; Bellanca and Bailey, 1975). In the California situation, follow-up investigations revealed that total chlorine residuals in the river at distances downstream from the discharge ranged from 0.2 mg/L to 0.3 mg/L. (This particular discharge required dechlorination in order to alleviate the fish-kill problem.) Extensive studies on the James River determined that the cause of fish kills was the chlorinated wastewater discharging from two sewage treatment plants. The lowering of chlorine feed concentrations at each plant almost completely eliminated fish kills.

Aside from these reported kills, information relating fish toxicity to chlorine discharges involves caged fish or bioassay studies. Servizi (1979) cited field studies in Maryland, Michigan and British Columbia that reported acute toxicity or absence of salmonids in receiving streams when total chlorine residuals were 0.02 mg/L or more in the receiver (Tsai, 1971; Basch, 1972; Servizi and Martens, 1974). Clarke et al (1977) found that mortalities of black bullheads (Ictalurus melas) caged in the Red River were greater when effluent from the north end municipal plant in Winnipeg, Manitoba, was chlorinated than when it was not. In continuous flow bioassays of chlorinated secondary effluent from the Brampton plant (Ontario), the 96-hr LC_{50} for rainbow trout ranged from 0.01 to 0.09 mg/L total residual chlorine (Cairns and Conn, 1979). One hundred and forty-nine domestic wastewater plants were studied in Virginia, Pennsylvania and Maryland in which fish community diversity and fish occurrence were related to observed total

residual chlorine (TRC) concentrations (Tsai, 1973). In streams receiving chlorinated effluent no living organisms were observed in the immediate vicinity of the outfall; no fish were found in water at TRC concentrations at or above 0.37 mg/L. The species diversity index fell to zero at a TRC concentration of 0.25 mg/L. Tsai's data further indicated that brown and brook trout did not occur at TRC concentrations above 0.02 mg/L.

Table 12 summarizes some of the field data collected during these freshwater investigations. For a more complete review, the works of Brungs (1973, 1976) and Servizi (1979) are recommended.

TABLE 12 SELECTED FIELD STUDIES DEMONSTRATING EFFECTS OF CHLORINATED SEWAGE ON AQUATIC LIFE. (Servizi, 1979) (Total Residual Chlorine)

Location	Species	Results
Maryland Pennsylvania Virginia	Numerous fish species including salmonids	Reduced diversity. Absence of Brook Trout and Brown Trout at 0.02 mg/L chlorine. James River, Virginia.
Michigan	Rainbow Trout	Toxic conditions at average chlorine of 0.014 mg/L and more.
California Sacramento River	Chinook (King) Salmon	Dechlorination installed to halt fish kills.
British Columbia	Sockeye Salmon Pink Salmon Coho Salmon Rainbow Trout	Mortalities common when chlorine in excess of 0.02 mg/L.
Ontario	Rainbow Trout	96-hr LC_{50} ranged from 0.01 to 0.09 mg/L residual chlorine in secondary treated municipal wastewater.

Servizi (1979) reported that in chronic, life-cycle toxicity tests using fathead minnows (Pimephales promelas) and two fish food organisms, a cladoceran (Daphnia magna) and an amphipod (Gammarus pseudolimnaeus) were exposed to dilutions of chlorinated secondary effluent. Daphnia magna was found to be most sensitive. The lowest mean concentration of TRC at which a measurable adverse effect occurred was 0.010 mg/L and the highest mean concentration at which no effect was observed was in the range 0.002 to 0.004 mg/L (Arthur et al, 1975). On the other hand, when exposed to chlorine in tap water, reproduction of the amphipod was affected at 0.0034 mg/L and Daphnia magna were killed by exposure to 0.001 mg/L (Arthur and Eaton, 1971; Brungs, 1973). In continuous flow bioassays using chlorinated secondary domestic wastewater, 30% mortality occurred among day-old Daphnia magna when exposed to 0.011 mg/L residual chlorine (Ward et al, 1976).

Chlorine residuals in the region of 0.2 mg/L were reported to cause significant damage to gill tissues of juvenile sockeye salmon (Oncorhynchus nerka) exposed to chlorinated sewage in a receiving stream for one hour. Gills of fish surviving 48 hours exposure showed changes in gill epithelia, including swelling, hypertrophy and necrosis (Servizi and Martens, 1974). The possibility cannot be overlooked that damage to gills may provide sites for infection. In a study of hatchery rearing ponds, Burrows (1964) observed that the susceptibility of salmon fingerlings to bacterial gill disease was closely associated with extensive epithelial hyperplasia caused by ammonia irritation. Bass et al (1977) and Cairns et al (1975) concluded that the primary mode of toxic action of residual chlorine was through gill damage leading to death by asphyxiation (Servizi, 1979).

Research into the toxicity of chlorine to freshwater algae is not very extensive. Brook and Baker (1972) noted that photosynthetic rate and respiration were depressed to 50% of control values at a TRC concentration of 0.32 mg/L. Respiration and photosynthetic rate were reduced to zero at 2.7 mg/L. Research by Brooks and Seegert (1977a) indicated that the photosynthetic rates of Lake Michigan phytoplankton were reduced by 25 to 100% following 30-minute exposures to chlorine concentrations ranging from 0.01 to 1.375 mg/L of TRC. The most significant reductions occurred at concentrations above 0.5 mg/L. Similar trends were found in chlorophyll a reductions.

The effects of chlorine on freshwater invertebrates is another area where literature is sparse. In general, the range of 96-hr LC_{50} values reported for invertebrates is much narrower than those reported for fish. With few exceptions, the 96-hr LC_{50} for invertebrates is about 0.10 mg/L of TRC (Brooks and Seegert, 1977b). Among the more

sensitive invertebrates tested were rotifers with 1-, 4- and 24- hr LC_{50} values of 0.032, 0.027 and 0.013 mg/L respectively (Grossnickle, 1974). Gregg (1974) investigated several invertebrate species over a range of 0.01 to 0.10 mg/L chlorine and found that mayflies were the most sensitive group tested while beetle larvae were the most resistant. Schneider et al (1975) observed that 96-hr LC_{50} values for crayfish were 0.96 mg/L; Authur (1971) indicated 7-day LC_{50} values greater than 0.78 mg/L for crayfish (Orconectes virilis).

Servizi (1979) pointed out that estuarine species have been the subject of laboratory bioassays in which residual chlorine concentrations as low as 0.005 mg/L were acutely toxic to oyster larvae (Crassostrea virginica) and clam larvae (Mercenaria mercenaria) in 48 hours (Roberts et al, 1975). Galtsoff (1946) reported that the pumping action of oysters was reduced at residual chlorine concentrations of 0.01 to 0.05 mg/L, and effectively stopped at 1.0 mg/L. A field survey reported that the heaviest recorded oyster spatfall in the James River estuary (Virginia) in ten years coincided with a large cutback in chlorine use at sewage treatment plants and led to speculation that chronic levels of chlorine may have been affecting larval stages of estuarine organisms far below detectable limits (Bellanca and Bailey, 1975).

When juvenile coho salmon were exposed to chlorinated primary treated municipal wastewater in continuous flow bioassays using seawater diluent, the 96-hr LC_{50} was 0.07 mg/L residual chlorine (Buckley, 1976). Thatcher (1978) exposed several marine species native to the Pacific Northwest to chlorinated seawater and reported residuals as Total Residual Oxidant (TRO) to account for hypobromous acid, hypobromite ion and bromamine formed during chlorination. TRO was considered comparable to residual chlorine in freshwater. Juvenile coho salmon were the most sensitive species tested with a 96-hr LC_{50} equal to 0.032 mg/L TRO. The 96-hr LC_{50}'s for juvenile Pacific herring (Clupea harengus) and English sole (Parophyrs vetulus) were 0.065 and 0.073 mg/L, respectively (Servizi, 1979).

Gentile et al (1973, 1976) observed a 55% decrease in adenosine triphosphate (ATP) content of marine phytoplankton exposed for 2 minutes to 0.32 mg/L residual chlorine and a 77% decrease after 45 minutes exposure to TRC concentrations as low as 0.01 mg/L. A 50% reduction in growth rates was observed for 10 species of marine phytoplankton exposed for 24 hours to chlorine residual concentrations that ranged from 0.075 to 0.25 mg/L. Table 13 lists some additional information on marine phytoplankton.

TABLE 13 SUMMARY OF TOXIC EFFECTS OF CHLORINATED WASTES ON MARINE PHYTOPLANKTON (DAVIS AND MIDDAUGH, 1978)

Species	Toxicant	Reported Chlorination Level (mg/L)	Duration of Test	Effect	Reference
Phytoplankton	Cl_2 injection	0.05- 0.40	12-hr + 4-hr incubation	50-98% loss of productivity	Carpenter et al. (1972)
Chlamydomonas sp.	sodium hypochlorite solution	0.69-12.90	5 min	reduced growth rate	Hirayama and Hirano (1970)
Skeletonema costatum	sodium hypochlorite solution	0.18- 2.40	5 min	none up to 0.29 mg/L; greater amounts inhibited growth	
Phytoplankton	sodium hypochlorite solution	0.32	2 min	55% decrease in ATP	Gentile et al. (1973, 1976)
		0.01	45 min	77% decrease in ATP	
		0.075- 0.25	24 min	55% decrease in growth	
Phytoplankton	Cl_2 injection		15 min	91% reduction in photosynthesis	Hamilton et al. (1970)

Larvae of two eastern crab species, Panopeus herbstii and Pagurus longicarpus, were exposed to chlorinated seawater (Roberts, 1978). The 96-hr LC_{50} for P. herbstii varied during the summer from about 0.024 mg/L to 0.12 mg/L of chlorine induced oxidant measured by amperometric titration. P. longicarpus larvae were less sensitive having a 120-hr LC_{50} equal to 0.050 mg/L chlorine induced oxidant (Servizi, 1979).

Muchmore and Epel (1973), Waugh (1964), McLean (1972, 1973), Turner et al (1948), James (1967), and Capuzzo et al (1976) investigated the effects of chlorination of wastewater on various marine invertebrates. The data listed in Table 14 indicate the lethal and non-lethal impact of various residual chlorine levels on a number of marine species.

4.1.2 Avoidance Reactions. The ability of fish to avoid harmful substances has been the subject of many studies. In laboratory tests to determine whether fish are able to detect and avoid chlorine, Sprague and Drury (1969) reported that juvenile rainbow trout avoided high and low concentrations of free chlorine but preferred intermediate concentrations (0.1 mg/L) which were lethal in about 4 days (Servizi, 1979). Katz and Harder (1976) suggested that the response reported by Sprague and Drury was not due to attraction but to the absence of chlorine residual at the gill surface owing to reaction between chlorine and ammonia secreted at the gill surface. As a result of laboratory studies using blacknose dace (Rhinichthys atratulus), a small minnow, it was concluded that these fish avoided chloramine solutions and residual chlorine in sewage at concentrations of 0.18 and 0.13 mg/L and above, respectively (Tsai and Fava, 1975). The mimic shiner (Notropis volucellus), river shiner (N. blennius) and bullhead minnow (Pimephales vigilax) avoided chloramines in a test chamber, with the former being the most sensitive and avoiding concentrations between 0.005 and 0.45 mg/L. The river shiner was least sensitive, avoiding chloramines only when the concentration reached 0.15 mg/L (Bogardus et al, 1975). Tests on rainbow smelt (Osmerus mordax), spottail shiner (Notropis hudsonius), alewife (Alosa pseudoharengus), yellow perch (Perca flavescens) and juvenile coho salmon (Oncorhynchus kisutch) concluded that avoidance of monochloramine is species specific and cannot be attributed to a rigid, precise code of behaviour (Bogardus et al, 1978). Coho showed the least tendency to avoid monochloramine at concentrations below 0.2 mg/L. A combination of schooling and territorial behaviour were believed to influence avoidance reactions among coho (Servizi, 1979).

TABLE 14 SUMMARY OF TOXIC EFFECTS OF CHLORINATED WASTES AND WATER ON MARINE INVERTEBRATES (FROM DAVIS AND MIDDAUGH, 1976)

Species	Toxicant	Reported Chlorination Level (mg/L)	Duration of Test	Effect	Reference
Strongylocentrotus purpuratus (gametes)	chlorinated sewage effluents	0.02	5 min	none	Muchmore and Epel (1973)
		0.11	5 min	100% inhibition of fertilization	
Urechis caupo (gametes)	"	0.2	5 min	22% inhibition of fertilization	
		1.0	5 min	100% inhibition of fertilization	
Phragmatopoma californica (sperm)	"	0.2	5 min	22% loss of motility	
		1.0	5 min	86% loss of motility	
Ostrea edulis	residual chlorine	10.0	48 min + 10°C	none	Waugh (1964)
Eliminius modestus	"	2.0	10 min	death and inhibited growth	
		5.0	3 min	none	
Balanus sp.	Cl_2 injection	2.5	5 min	80% mortality	McLean (1972, 1973)
Acartia tonsi	"	2.5	5 min	90% mortality	
Melita nitida	"	2.5	5 min	near 100% mortality 96 hr after exposure	
Palaemonetes pugio	"	2.5	5 min	near 100% mortality 96 hr after exposure	

TABLE 14 SUMMARY OF TOXIC EFFECTS OF CHLORINATED WASTES AND WATER ON MARINE INVERTEBRATES (FROM DAVIS AND MIDDAUGH, 1976) (Cont'd.)

Species	Toxicant	Reported Chlorination Level (mg/L)	Duration of Test	Effect	Reference
Bimaria franciscana		4.5	4 days	none	
Anemones	residual chlorine	10.0	1,2,4,8-hr/ day for 10 days	none	Turner et al. (1948)
		2.5	5 days	100% mortality	
		1.0	15 days	100% mortality	
Mussels	"	10.0	1,2,4,8-hr/ day for 10 days	95-100% mortality	
		2.5	5 days	100% mortality	
		1.0	15 days	100% mortality	
Barnacles	"	10.0	1,2,4,8-hr/ day for 10 days	95-100% mortality	
		2.5	4 days	100% mortality	
		1.0	7 days	100% mortality	
Mytilus edulis	Cl_2 injection	0.02-0.05	a few hours	detachment and migration	James (1967)
Homarus americanus	free chlorine	2.02	48-hr	50% mortality	Capuzzo et al, (1976)
	chloramine	0.56	48-hr	50% mortality	
Crassostrea virginicia (larvae)	residual chlorine	0.005	48-hr	50% mortality	Roberts et al, (1975)
Crassostrea virginicia (juvenile)	residual chlorine	0.023	96-hr	50% mortality	

Although some fish may avoid lethal chlorine concentrations under laboratory conditions, Servizi and Martens (1974) concluded that mortalities occurred among rainbow trout near a chlorinated primary sewage discharge and suggested that fish will not necessarily avoid lethal concentrations of chlorinated municipal sewage under field conditions even though free to do so. A further indication that fish failed to avoid toxic chlorine residuals in the field was seen in the James River, where it was hypothesized that broken backs among many adult fish were caused by low level chronic doses of chlorine (Bellanca and Bailey, 1975). Brungs (1976) suggested that the absence of trout in the vicinity of chlorinated discharges, as reported by Tsai (1971), may indicate avoidance; in some cases mortalities may occur on an attrition basis as individual fish seek food and territory in the receiving stream. Thus while large fish kills may not occur, and single mortalities may not be noticed, over a year the accumulated mortality may be significant (Servizi, 1979). Additionally, where avoidance does occur, (Chamut, 1981) it may:

i) result in a reduction in the amount of available habitat;
ii) result in displacement to less favourable habitats with subsequent impacts on productivity; and/or
iii) interfere with the migratory success of fish (e.g. upstream and downstream salmon migrations).

Meldrim et al (1974) and Meldrim and Fava (1977) using flowing water bioassays, studied the effect of chemical pollutants on estuarine organisms. They found that white perch, Monone americana, consistently avoided 0.08 mg/L total residual chlorine at temperatures from 7 to 17°C. Silversides, Menidia menidia, also avoided 0.08 mg/L residual chlorine at temperatures from 8 to 28°C, but showed preference for 0.08 mg/L residual chlorine when fish that had been acclimated to 7°C were exposed at 12°C. Middaugh et al (1977) also demonstrated temperature-dependent avoidance reactions with juvenile spot, Leiostomus xanthurus. At 10°C a concentration of 0.18 mg/L was required for significant avoidance; at 15 and 20°C, spot showed significant avoidance of residual chlorine concentrations as low as 0.05 mg/L.

In review, the range and diversity of information on the lethality of chlorinated effluents indicate that several factors influence toxicity in the aquatic environment. Evidence suggests that the biological effects from exposure to chlorinated effluents vary with the aquatic species, water quality characteristics (freshwater or marine) and the characteristics of discharged effluent. Because each discharge varies in

terms of these characteristics, site-specific resolution of the effect of chlorinated discharges on the environment is required.

4.1.3 Chlorinated Organic Compounds. The formation of chlorinated organic compounds as a result of the disinfection of sewage effluents has been reported by several authors (Glaze et al, 1973, 1975, 1978; Jolley, 1973, 1974, 1975; Jolley et al, 1978a, 1978b; Sievers et al, 1978; Harrison et al, 1976; Morris, 1975; Gaffney, 1977). In particular, the laboratory work of Jolley (1974) involved the chlorination of secondary sewage effluents treated to 1 mg/L chlorine residual with ^{36}Cl-tagged chlorine gas or hypochlorite solution. The reaction products identified by Jolley were of three classes: phenols, purines and pyrimidines, and aromatic acids.

Gehrs et al (1974) undertook aquatic toxicity investigations with two of these compounds, the pyrimidine, 5 chlorouracil and a phenol, 4-chlororesorcinol. The two compounds decreased the hatchability of carp (Cyprinus carpio) eggs at concentrations as low as 0.001 mg/L. Subsequent investigation by Eyman et al (1975) showed positive correlation between the concentration of 5-chlorouracil and percent malformation in newly-hatched carp larvae when they were exposed to 0.5 mg/L or more of the substance. Later, however, tests of a seventeen-compound composite mixture containing chloro-organics (including 5-chlorouracil and 4-chlororesorcinol) in the proportions originally identified by Jolley in sewage effluent, produced no significant effects on carp embryos at concentrations up to 10 mg/L (Gehrs and Southworth, 1978). The investigations suggested that a complex antagonistic interaction might have affected the results. Trabalka and Burch (1978) pursued this hypothesis using synthetic chlorinated effluents. They concluded that the chloro-organic mixtures were acutely toxic to carp (Cyprinus carpio) embryo and Daphnia pulex at levels approximately three orders of magnitude greater than those expected in actual effluents and that toxicity was primarily attributable to its chlorophenol content. A follow-up study (Trabalka et al, 1980) demonstrated chronic toxicity to D. pulex at a concentration of 10 mg/L (synthetic mixture of chemicals), which was still 2 orders of magnitude greater than concentrations reported for actual effluents. Thus, the chlorinated organics that have been examined do not appear to be of particular environmental concern with respect to the type of freshwater aquatic species tested. Unless other aquatic organisms are much more sensitive and/or significant bioaccumulation of the 17 tested compounds can occur, the particular assemblage of compounds tested may not prove to be an important environmental problem.

In chlorinated seawater, Scott et al (1980) observed a threefold bioconcentration of bromoform ($CHBr_3$) in oyster (Crassostrea virginica) tissue compared to levels detected in the water. After exposure, $CHBr_3$ was rapidly depurated (48 hours). Gibson et al (1980) found that molluscs generally reflected water concentrations of $CHBr_3$ in their tissue, whereas menhaden (Brevoortia tyrannus) and shrimp (Penaeus aztecus) showed a tendency to concentrate $CHBr_3$ by a factor of 3 to 50 above ambient concentrations.

Based upon these limited data, the determination of the overall impact of chlorinated organics on aquatic ecosystems is not possible. Many chlorinated organic fractions of municipal effluents remain to be identified and studied to further assess possible environmental concerns.

4.2 Wastewater Discharges to Land

Land disposal of wastewater has been extensively studied in recent years. To wastewater treatment authorities, land disposal offers an alternative to the surface water discharge of treated wastewater. It may also facilitate conservation of water resources.

Sewage treatment, combined with chlorination of the effluent prior to land application, is desirable microbiologically, since proper treatment will reduce the number of pathogenic microorganisms present. However, as discussed earlier, chlorination also results in the formation of a wide range of chlorine- and other halogen-containing derivatives which can then be found in the wastewater effluent (Jolley, 1975).

Among all constituents of concern in a land disposal system, toxic chemicals (i.e. stable organic substances and trace metal elements) are the least understood. Little attention has been focused on the impact of these potentially hazardous substances on a land disposal system or on reuse of the water.

Soils seem to possess the ability to attenuate the input of toxic chemicals through various mechanisms. With existing data it is difficult to project the long-term effectiveness and the consistency of the soil mantle required to immobilize and detoxify hazardous substances found in wastewater. Therefore, for long-term, full-scale, land disposal operations, it is essential that the fate of toxic chemicals during the land disposal not be overlooked. Some of these considerations are reviewed in the following subsections.

4.2.1 Nature of Contaminants

4.2.1.1 Microbiological. A review of the potential microbiological problems associated with the application of wastewater to land has been discussed in Section 3.2.3.4. For additional information Larkin et al (1978) may be consulted.

4.2.1.2 Metals. Numerous studies have been conducted in recent years on both effluents and sludges containing metals (Canada-Ontario Agreement (COA), 1978b; Sidle et al, 1976; Palazzo, 1976). In most instances, the use of sewage sludges is of more concern than the use of wastewater unless the wastewater is heavily contaminated and application rates are high. For example, treated wastewaters may contain cadmium at less than 20, or at the most 30 parts per billion (ppb), while sludges contain this element in the parts per million (ppm) range, with upper limits of 500 ppm or more reported (COA, 1978b). Although much more wastewater than sludge is applied to a given land area, this difference is not large enough to make up for the higher concentrations of cadmium in sludges. Various provincial agencies have developed guidelines which limit the application of metals to soil during sludge disposal operations. It would seem unlikely that these limits would be violated in a wastewater irrigation operation; however, the method and frequency of application of wastewater effluents to crops could induce a build-up of metal concentrations on foliage. Accumulation of heavy metals in the soil can result in soil sterility.

4.2.1.3 Organic contaminants. The presence of organic contaminants is a matter of considerable concern, partly because of the lack of sufficient research and study and partly because many of these contaminants are toxic and potentially carcinogenic, teratogenic, or mutagenic to humans.

In addition to chlorinated organics which may be generated in disinfection processes, other organic compounds may be present in the raw wastewater and eventually pass through the treatment system. Insecticides, herbicides and industrial chemicals are some examples of the type of substances present in municipal wastewater.

4.2.2 Mechanisms of Potential Food Contamination

4.2.2.1 Physical contamination. Chaney and Lloyd (1979) have shown that sewage sludges are effectively retained when applied to vegetation by spraying, and that they are not completely removed by rain. Because of the more dilute nature (and lower viscosity) of wastewater and effluents, lower contamination levels on vegetation would be expected.

However, evaporation and repeated application may provide sufficient buildup of contaminants to be a cause for concern. Contaminants physically retained on crops may be ingested by animals, or possibly directly by humans, if improper practices are followed (Bryan, 1974).

4.2.2.2 Uptake from soil. Much research has been conducted on the uptake of metals such as cadmium, lead, zinc, nickel, and copper from soils.

Limited research on the uptake of organic chemicals from soils has been undertaken. Nash (1974) and Nash and Harris (1973) have shown that some pesticides (chlorinated hydrocarbons) are taken up by plants, but others are not or are taken up at very low levels. Uptake of PCB's by root crops has been demonstrated by Iwata and Gunther (1976) under field conditions.

4.2.2.3 Foliar uptake. The subject of foliar uptake and translocation of sewage-borne contaminants by plants and food crops is an area of considerable interest, but few if any direct research studies have been conducted. The development and evaluation of commercial herbicides, however, has prompted extensive studies on the relationship between chemical structure, physical properties, and the behaviour of these chemicals in and on plants. Although no simple relationship was found between the variables involved, it is apparent that many chemicals are effectively taken up from leaves, and that others are also taken up via roots or shoots. Some compounds may be retained in the area to which they are applied or may be readily translocated to other parts of the plant (Braude et al, 1978).

As in many processes of this type, the concentration of the particular contaminant in the liquids or wastes applied is of importance in foliar uptake and very low concentrations do not appear to be a major cause for concern. A possible exception here would be extraction or transport phenomena by which such substances would be selectively removed and retained by the cuticle on crop and plant leaves (Braude et al, 1978).

4.2.2.4 Direct Uptake by Food Animals. Cattle and other animals ingest soil as well as plants while grazing. Chemical contaminants may build up in selected tissues of such animals when sewage sludge is used on land and pastures. Although wastewaters may present a lesser problem, those from highly contaminated sources may result in the buildup of contaminants in the surface layer of the soil similar to that observed with sludges.

Use of wastewater on land and the resulting impact on the environment has primarily been investigated with respect to microorganism and inorganic chemicals contamination. Limited research has been conducted on organic contaminants and their effect on crops, animals and humans. Efforts should continue in this area.

4.3 Conclusions

1) A great deal of laboratory information exists on the acute and chronic effects of residual chlorine on aquatic organisms. However, there is little in situ documentation of identified residual chlorine problem areas in Canada. Consequently, the environmental benefits of reducing or eliminating such discharges in terms of protecting aquatic life are difficult to quantify.
2) Residual chlorine is acutely toxic to aquatic organisms at levels as low as 0.02 mg/L. Chronic toxicity has been evidenced at levels in the order of 0.001 mg/L.
3) Residual chlorine is not as directly toxic to freshwater algae and invertebrates as it is to fish. However, as evidenced in Table 2, residual chlorine levels currently discharged from municipal wastewater plants are high enough to eliminate fish food species in the immediate downstream areas of municipal outfalls.
4) Research into the toxicity of residual chlorine to saltwater and estuarine species has not been as extensive as that on freshwater organisms. The toxic impact is believed to be comparable to that on freshwater species.
5) Chronic chlorine levels may affect oyster larvae (Crassostrea virginica) far below detectable limits. Very few studies concerning the effects of chlorine on shellfish exist. The limited studies indicate adverse effects on feeding behaviour and activity.
6) Marine phytoplankton are adversely affected by chlorine concentrations normally discharged from municipal outfalls to saltwater.
7) Avoidance of residual chlorine by fish in a freshwater environment is species specific and cannot be relegated to a precise code of behaviour. A combination of schooling and territorial behaviour is believed to influence avoidance. In some cases, mortalities occur as fish seek food and territory in a stream receiving chlorinated wastewater.
8) In the marine environment, avoidance reactions to chlorinated seawaters appear to be species specific and temperature dependent.

9) Based upon limited data, final determination of the impact of chlorinated organics on aquatic ecosystems is not possible. Chlorinated organics tested thus far do not appear to be of particular environmental concern to the type of freshwater species tested.

10) The discharge of municipal wastewaters to agricultural and recreational lands is a practice that is being promoted in various regions of the country. Irrigation of wastewaters reduces pollutant loadings to surface waters, recharges groundwaters and supplements the water supply requirements of agricultural crops and other vegetation. Although provincial guidelines detail siting requirements, wastewater application rates and land use, most of the concern has been directed to microbiological and metals loadings. Little research has been conducted on the effects of organic contaminants on irrigated lands and crops and the resulting impact on man and animals.

5. STRATEGY FOR WASTEWATER DISINFECTION PRACTICES IN CANADA

Municipal effluents are an identifiable source of pathogenic contamination which can represent a direct or indirect threat to human health. Disinfection processes used to deal with this threat may themselves create new hazards to human health or cause significant adverse responses in the aquatic environment. It is difficult for universal policies on wastewater disinfection to effectively deal with this apparent conflict and for this reason site-specific resolution is required.

More specifically:

1) The need for and application of microbiological controls over pathogen contaminated point and non-point discharges must be approached on a site-specific basis with due consideration for receiving water use and the potential risk to human health as identified by microbiological water quality criteria.

2) The extent to which potential health hazards may be alleviated by wastewater management alternatives and operational controls and/or the design and location of outfalls must be examined.

3) Where wastewater disinfection is required, it must be practised in a manner which ensures effective control of the hazard.

4) The potential for adverse effects of the disinfectant residuals and by-products on human health and the aquatic ecosystem must be identified and, where necessary, suitable remedial measures should be implemented.

Resolution of the need for municipal wastewater disinfection at a site involves the investigation of receiving water uses and the associated risks to human health, an assessment of the options that are available for the control of fecally-contaminated discharges and an evaluation of the environmental effects that control measures may precipitate. Figure 3 illustrates the type of rationalization that should be involved in assessing the need for, and consequences of, disinfecting municipal wastewaters. In jurisdictions that take the regulatory approach of universal disinfection of all municipal wastewater effluents (allowing relaxation only when the proponent provides a well substantiated case for exemption or modification of the disinfection requirement), Figure 3 should be used to evaluate the need for policy relaxation. In the other jurisdictions which take a site-specific regulatory approach, the outlined review process should be used routinely for each case under consideration.

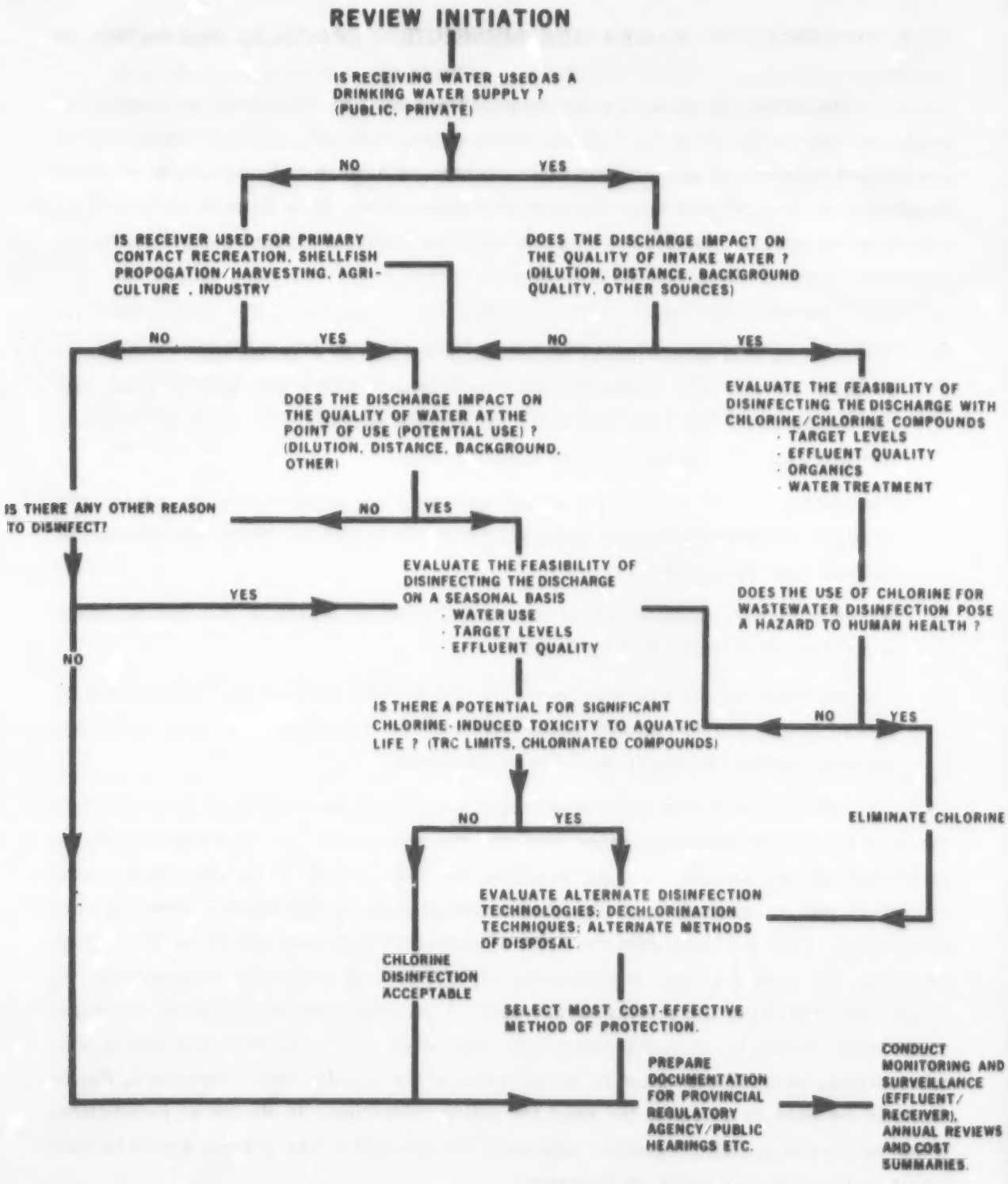
REVIEW INITIATION
IS RECEIVING WATER USED AS A DRINKING WATER SUPPLY ? (PUBLIC, PRIVATE)
NO
YES
IS RECEIVER USED FOR PRIMARY CONTACT RECREATION, SHELLFISH PROPOGATION/HARVESTING, AGRICULTURE , INDUSTRY
DOES THE DISCHARGE IMPACT ON THE QUALITY OF INTAKE WATER ? (DILUTION, DISTANCE, BACKGROUND QUALITY, OTHER SOURCES)
NO
YES
NO
YES
DOES THE DISCHARGE IMPACT ON THE QUALITY OF WATER AT THE POINT OF USE (POTENTIAL USE) ? (DILUTION, DISTANCE, BACKGROUND, OTHER)
EVALUATE THE FEASIBILITY OF DISINFECTING THE DISCHARGE WITH CHLORINE/CHLORINE COMPOUNDS
· TARGET LEVELS
· EFFLUENT QUALITY
· ORGANICS
· WATER TREATMENT
IS THERE ANY OTHER REASON TO DISINFECT?
NO
YES
EVALUATE THE FEASIBILITY OF DISINFECTING THE DISCHARGE ON A SEASONAL BASIS
· WATER USE
· TARGET LEVELS
· EFFLUENT QUALITY
YES
NO
DOES THE USE OF CHLORINE FOR WASTEWATER DISINFECTION POSE A HAZARD TO HUMAN HEALTH ?
IS THERE A POTENTIAL FOR SIGNIFICANT CHLORINE-INDUCED TOXICITY TO AQUATIC LIFE ? (TRC LIMITS, CHLORINATED COMPOUNDS)
NO
YES
ELIMINATE CHLORINE
NO
YES
EVALUATE ALTERNATE DISINFECTION TECHNOLOGIES; DECHLORINATION TECHNIQUES; ALTERNATE METHODS OF DISPOSAL.
CHLORINE DISINFECTION ACCEPTABLE
SELECT MOST COST-EFFECTIVE METHOD OF PROTECTION.
PREPARE DOCUMENTATION FOR PROVINCIAL REGULATORY AGENCY/PUBLIC HEARINGS ETC.
CONDUCT MONITORING AND SURVEILLANCE (EFFLUENT/ RECEIVER), ANNUAL REVIEWS AND COST SUMMARIES.

Figure 3 FRAMEWORK FOR EVALUATING SITE-SPECIFIC WASTEWATER DISINFECTION REQUIREMENTS.*

*SUBJECT TO JURISDICTIONAL POLICY AS DISCUSSED ON PAGE 71.

In general, the framework indicates that human health risks are the initial concern of the reviewer and, upon establishing the level of risk involved and the potential for reducing or eliminating the risk, the environmental considerations determine the suitability of the proposed controls. Upon development of an option that satisfies both the human health and environmental concerns at the specific site, a monitoring and surveillance program is instituted to measure the impact of the discharge on the environment and the effectiveness of the control measures in protecting human health.

The following discussion reviews many of the points which have been examined in earlier chapters of this report. The human health concerns and environmental aspects of the site-by-site evaluation process are outlined and some guidelines for decision-making are offered.

5.1 Human Health Risk Assessment

One topic which has been discussed extensively in the preceding chapters of this report is the use of coliform organisms as water quality indicators. The use of indicator organisms has been criticized because of the poor correlation between levels of coliform bacteria and pathogens in surface waters and the relationship between coliform bacteria and infection and disease among water users. The development of a more reliable and accurate method of assessing potential health hazards has been identified as an essential element in resolving the question of the need and utility of wastewater disinfection. A more definitive indicator should:

i) be consistently and exclusively associated with the source of the pathogens;
ii) be present in sufficient numbers to provide an "accurate" density estimate whenever the level of any of the pathogens is such that the risk of illness is unacceptable;
iii) approach the resistance to disinfectants and environmental stress, including deposited toxic materials, of the most resistant pathogen potentially present at harmful levels in the source, and
iv) be quantifiable in recreational waters by reasonably facile and inexpensive methods and with considerable accuracy, precision, and specificity.

It is doubtful that any one organism can meet all of the requirements. At present, the use of total coliforms and fecal coliforms as indicators is stipulated in provincial water quality regulations or guidelines. The use of these indicators will continue until a better method of measuring water contamination has been developed.

Nevertheless, the scope of information obtained and hence the range of water quality measurements made and indicators employed should be increased to test for deteriorating waters and potential health hazards. The choice of organisms used will depend upon the waters tested and the water use. In this manner a health effects water quality system which indexes the potential risk of infectious disease coincident with man's use of the aquatic environment may eventually be developed.

The potential for human contact with waterborne pathogens is greatest for the following receiving water uses: raw water supply sources; recreational waters; irrigation waters, and waters used for shellfish propogation and harvesting. Disinfection of wastewater effluents that are discharged into waters having any one or a combination of these uses does not automatically provide the necessary protection to human health. Other considerations such as the location (and design) of wastewater outfalls, the level of pretreatment provided at municipal wastewater plants, and the quality of effluents being discharged from other point and non-point sources along the water course also directly affect the receiving water use and thus indirectly the need for and the utility of disinfecting a wastewater effluent.

The background quality and hydrologic characteristics of receiving waters can also have a significant effect on the survival of pathogens entering the environment. Stream self-purification processes are dependent upon sedimentation, predation, dilution, water temperatures, solar radiation, etc. The effectiveness of the natural processes is time dependent, and therefore the flow time between input and reuse becomes an important variable at each site. Mitigating circumstances that may counterbalance the beneficial effects of these natural processes include discharges of industrial wastes (i.e. food processing and paper mill wastes) that provide excessive nutrients to micro-organisms, stormwater runoffs characteristic of the surrounding watershed, and the magnitude of pollutant loading from all discharges. Therefore, while natural self-purification may be effective in a given water course during periods of warmer temperatures and limited conditions of precipitation, results may be less impressive during other seasons or precipitation conditions.

Recognizing these inconsistencies, it is necessary that decisions regarding the need for wastewater disinfection be made on a case-by-case basis with reference to receiving water use and the aforementioned variables rather than enforcing an arbitrary uniform standard for all discharges. Ideally, careful seasonal studies are required to determine indicator bacteria and pathogen survival rates within the receiving stream,

under a variety of treatment plant conditions (i.e. with and without disinfection processes). The results of these investigations will indicate one of three requirements:

1) year-round disinfection;
2) disinfection on a seasonal basis, or
3) disinfection is not required.

Arbitrarily, at least three situations can be identified in which disinfection of a treated effluent is not required:

1) If the wastewater treatment system includes unit operations with an established capability to consistently achieve the designated effluent limitations or better, without a terminal disinfection stage. (Effluent limitations vary from jurisdiction to jurisdiction, but as stated in Section 2, a limitation of 2500 TC/100 mL, or 200 FC/100mL, is probably indicative of the capability of disinfection (chlorination) processes designed and operated to existing standards).
2) If the treated effluent discharges to receiving waters which are unsuitable for recreational, agricultural or raw water supply usage because of natural or manmade background water quality conditions.
3) If there is no identifiable usage of receiving waters which represents a potential health risk to the public, (e.g. remote or isolated installations; discharges to the ocean).

The quality of the effluent is one other factor that should be considered when assessing the utility of disinfecting an effluent. Raw sewage, low quality primary effluents, combined sewer overflows and stormsewer discharges, and certain types of industrial effluents are not amenable to disinfection, (as defined by the limits cited in item (i)), or may require excessively high chlorine dosage levels (over 25 mg/L) with poor disinfection results. Massive doses of chlorine are no substitute for adequate pretreatment of wastewater, and in situations where poor pretreatment practices occur, continuous disinfection of the low quality effluents is of questionable benefit.

When a discharge cannot be categorized under one of the above-indicated critera, additional site-specific details must be examined before a final decision on a year-round, seasonal, or nondisinfection requirement can be made. There are two alternatives that may be employed to develop these details. One approach is for the regulatory agency to stipulate year-round disinfection requirements at all wastewater

plants, allowing exemptions only on the basis of data supplied by the owners of wastewater treatment plants or other interested/concerned groups. The other strategy involves the regulatory agency or proponent (to the satisfaction of the regulatory agency), conducting its own investigative studies on a case-by-case basis and resolving the need for disinfection at each effluent outfall. The former strategy is perceived to minimize public health risk in that disinfection of municipal plant effluents is initially required in all cases. Exemptions are granted to municipalities or private owners when they are able to show that risk to human health is not affected by relaxation of disinfection on a seasonal or on a year-round basis. With the latter strategy the need to disinfect a municipal effluent is reviewed in each case. The responsible provincial agency examines the potential threat to public health and decides whether disinfection is required. Adoption of this approach eliminates the situation where wastewater treatment plants disinfect only because owners are unable or unwilling to make the effort to assess the need for wastewater disinfection, and minimizes the discharge of disinfectant residuals and byproducts to the environment.

Monitoring programs should be instituted at points of discharge and at points of receiving water use to assess any changes in water quality as a result of wastewater disinfection/non-disinfection practices. Frequency of monitoring will depend on the receiving water use and its history.

Discussion follows on the additional concerns that should be considered in the evaluation of receiving waters and associated uses.

5.1.1 Raw Water Supply. Disinfection of wastewater effluents should not be construed as a guarantee that pathogen-free surface waters will be available at water intakes for private or public potable water systems. Water treatment plants must be considered as the final barrier against waterborne disease transmission via the potable water route and these plants must be designed and operated in a fail-safe manner. They must incorporate water treatment technology that is capable of producing high quality drinking water under the most adverse raw water pollutant loading and water demand conditions anticipated at a specific site.

5.1.2 Recreational Waters. When a wastewater effluent discharges into waters used for recreation, the violation of water quality objectives for primary contact recreation is a potential concern. Seasonal disinfection of municipal discharges may be a viable method of maintaining water quality objectives during the recreational season. During

non-swimming seasons, contact recreation will not be occurring and therefore the need for disinfection will depend upon other water uses.

On those streams that require only seasonal effluent disinfection to protect a downstream bathing area, the date for initiating disinfection practices should be 8 weeks before the seasonal bathing period starts. The purpose of the early spring start for disinfection is to allow gradual phasing-in of the process to ensure accurate evaluations of the application requirements are made and thereby avoid wasteful and environmentally dangerous practices. Extending the closing dates for disinfection in late summer will protect weekend recreational uses of bathing areas during periods when the water temperature may still be warm.

The Federal-Provincial Working Group on Recreational Water Quality, in the draft report entitled, "Guidelines for Canadian Recreational Water Quality" (HWC, 1980), makes the following statement:

"The determination and enumeration of fecal coliforms is the most widely accepted method for monitoring fecal contamination of recreational waters. The proposed maximum limit specifies a geometric mean of not more than 200 fecal coliforms per 100 mL from a series of not less than 5 samples taken over a 30-day period. The fecal streptococcus test is a valuable support parameter used to develop the fecal coliform: fecal streptococcus ratio as an indication of the type (human or non-human) of fecal pollution. Total coliform measurements are not included in the guidelines for recreational water quality, but occasional monitoring may be useful for historical purposes or for water quality surveys by environmental workers.

"The presence of disease-causing organisms, e.g. Pseudomonas aeruginosa, Staphylococcus aureus, Candida albicans, Salmonella, Shigella or viruses, in recreational waters constitutes a potential health hazard for swimmers. Sampling is indicated when there is evidence of water-borne disease among bathers, or when there is need to assess possible hazards at heavily-used beaches especially during periods of low water and high temperatures. Monitoring for pathogens should be undertaken only by well-equipped laboratories with experienced personnel."

In addition to the above limits, the Guideline states that "...any sample yielding more than 400 fecal coliforms/100 mL should be investigated. Minimum action consists of immediate resampling of the site".

The proposed Guideline, while emphasizing domestic wastewater contamination, recognizes the possibility of non-human and non-enteric contamination of recreational waters. Such an approach is supported by this Working Group.

5.1.3 Irrigation Waters. The use of low quality wastewater effluents for irrigation of recreational lands or lands to which the public has uncontrolled access is not an acceptable practice. In these situations, the bacteriological quality of irrigated effluents should be at least equivalent to criteria specified for primary contact recreation. Disinfection of the effluent, or retention in holding ponds, will be required to meet these objectives. Because of the potential phytotoxic effect of chlorinated effluents, holding ponds are preferable, and in fact, more practical in an irrigation operation.

Opinions differ on the acceptability of wastewater effluents for irrigation of agricultural lands. Some provincial agencies allow low quality (primary) effluents to be applied to agricultural lands, other agencies maintain a minimum requirement of secondary treatment in all cases. For applications to recreational lands, or lands used as pasture for dairy or beef cattle, secondary treatment followed by storage and/or disinfection may be required.

Currently, sewage effluents are not being used for irrigation of food crops which are consumed by the public. With the readily available supply of surface waters for the purpose of irrigation in most situations, there is no need in Canada to take the risk of some failure occurring in the treatment process or of offending the aesthetic sensibilities of the consumer.

5.1.4 Shellfish Waters. For Canadian shellfish-growing waters a mean fecal coliform MPN limit of 14/100 mL has been adopted as the national standard. Municipal discharges to shellfish-growing waters may violate this target level and result in the closure of shellfish beds from harvesting. The economic and social impact of such closures must be addressed locally and decisions on wastewater discharges made accordingly. A practical alternative to wastewater disinfection may be the avoidance of direct discharges to waters used for shellfish propogation and harvesting.

One fact that must be borne in mind when considering the disinfection of discharges is that shellfish are vulnerable to low concentrations of residual chlorine. Dechlorination of a chlorinated effluent may be required in order to avoid detrimental impact on the shellfish community.

Bacteriological contamination of other fisheries resources by wastewater effluent discharges is not a proven problem. Oxygen demand as a result of the respiration demand of large bacterial populations may reduce dissolved oxygen levels in receiving waters to a concentration that is critical to fish and other aquatic life. This conditon would normally be a local phenomenon.

5.2 Environmental Considerations

Once the decision has been made to disinfect a municipal discharge, determination of the potential impact on biota in the receiving environment must be made. The assessment of the impact of disinfected effluents on a fisheries resource is the responsibility of resource managers. The potential for disinfectant induced toxicity to aquatic life will dictate: the acceptability of the proposed disinfection process; the requirement for detoxification of the effluent prior to discharge; the need for non-toxic disinfection alternatives; the feasibility of relocating the effluent outfall; or the development of an alternate method of wastewater disposal. Although the specifics of an environmental evaluation are beyond the scope of this report, a review of major items of concern is warranted.

5.2.1 Temperature. Temperature strongly influences the resistance of fish to chlorine. The resistance of fish exposed intermittently to chlorine is inversely related to temperature (Brooks and Seegert, 1977b; Seegert and Brooks, 1978; Seegert et al, 1979). Although less of a factor during long exposures, the resistance of fish continuously exposed to chlorine is also inversely related to temperature (Thatcher et al, 1976; Rosebcom and Richey, 1977); LC_{50} values of fish exposed to chlorine were found to be twice as high at low temperatures (eg. 10°C) than for the same fish species at warmer temperatures (eg. 20 to 30°C).

5.2.2 Dilution. If characteristics of a receiving body are such that rapid dilution of disinfectant byproducts and residuals to non-toxic levels is inevitable, then advantage should be taken of this parameter. Site-specific characteristics will dictate the best location and design of an outfall to protect the receiving environment.

5.2.3 Chlorine Species. Each of the chlorine species has a unique toxicity rating and therefore it is important to know which species will be found under various environmental conditions. In most freshwaters, monochloramine will be the dominant species, but under the right conditions (i.e. Cl_2:NH_3 ratio approaching 2:1; pH less than 7.0) dichloramine can

be formed. Dichloramine has been found to be two to three times more toxic than monochloramine (Thomas et al, 1980).

Free chlorine is more toxic than the chloramines by 3 to 14 times (Heath, 1977). At a Cl_2:NH_3 molar ratio greater than 2:1, free chlorine is the dominant species.

5.2.4 **pH.** As discussed above, pH plays a role in chlorine toxicity by affecting the relative proportions of the various chlorine species.

5.2.5 **Chlorine Demand.** Chlorine demand in the receiving water is a parameter that may be utilized to the benefit of the environment. Dilution of effluents should be maximized in waters having a high chlorine demand if the chlorine is being reduced to an innocuous form (i.e. Cl^-).

5.2.6 **Exposure Time and Chlorine Concentration.** Mattice and Zittel (1976), Thayer et al (1978), and Turner and Thayer (1980) have developed toxicity models that incorporate both exposure time and chlorine concentration parameters which define safe levels of exposure to various species of fish. Like most models, these developments do not take into account site-specific characteristics which may require more restrictive or less restrictive limits than the models predict.

5.2.7 **Species Sensitivity.** Studies covering the resistance of fish to chlorine have shown that resistance may be similar for fish of the same species but dissimilar at the family level (i.e. LC_{50} values for rainbow and brook trout may be similar whereas LC_{50} values for brook trout and carp may differ by 2 to 3 times). This emphasizes the fact that the testing of important indigenous species should be undertaken at the family level, and where possible, at the genus level.

5.2.8 **Avoidance Behaviour.** Avoidance behaviour is an area where greater emphasis should be placed when assessing the environmental impact of an effluent. Avoidance studies should be initiated which concentrate on field applications, testing of groups of fish rather than single individuals and determining under which circumstances (e.g. thermal; habitat preference) the avoidance mechanism fails.

5.2.9 **Resiliency of the Biotic Community.** What degree of mortality is biologically acceptable is a difficult question to address. The loss of a few individuals, or a small percentage of a population, will not disrupt the entire ecological balance in most situations, yet it is difficult to accurately predict the potential loss. Several definitions of mixing zones or limited use zones for point discharges to surface waters have been

developed and these definitions describe areas in receiving waters in which degradation of water quality criteria will be allowed to proceed. This type of approach is based on the rationale that some of the receiving water biota may be sacrificed without undue harm to the ecosystem. The acceptability of this approach as opposed to the alternative of allowing only non-lethal discharges to occur is something that resource managers must resolve on a site-specific basis.

5.2.10 Effects of Chloro-Organics. There has been a great deal of research activity associated with the assessment of chlorinated hydrocarbons and their effects on man and other animal populations. Studies indicate that chlorinated wastewater effluents are a source of chlorinated organic compounds that may .. accumulate in fish or that may be candidate substrates for chlorine-derived mu.. ns. The question of the degree and extent of environmental contamination with halogenated organics is currently being asked. Emphasis is being placed on the assessment of complex mixtures of chemicals since this is essentially the make-up of effluent discharges to the environment. The health and environmental impact of such complexes in the aquatic environment is not known at this time. High priority should be given to further research in this area. Estimating the potential for increased risk of adverse human health and environmental effects is the ultimate goal of this research. This implies a quantitative estimate that could be used in the balancing of risks with benefits for various disinfection technologies.

Many organic compounds are capable of imparting objectionable tastes and odours to water, fish flesh and other aquatic organisms at levels far below those otherwise considered detrimental to the aquatic environment. As a group, the chlorinated phenols have been identified as the halogenated organic compounds with the highest organoleptic properties. Shumway and Palensky (1973) demonstrated that the susceptibility of fish towards the accumulation of tainting substances depended upon the species of fish tested, the nature of the pollutant and on the length of exposure. Of the chlorinated compounds tested, the estimated threshold concentration (ETC - the highest estimated concentration of material that will not impair the flavour of the flesh of exposed fish) ranged from 0.4 ppb for 2,4-dichlorophenol to 84 ppb for 2,3 - dichlorophenol.

Effects of chloro-organics on eggs, larvae and the reproductive behaviour of fish is a topic that few researchers have attempted to determine, perhaps because of the difficulties involved with such studies. Further investigations are required in this area.

6. RESEARCH ACTIVITIES AND NEEDS

6.1 Research Activities

Information on current research activities has been collected from provincial and federal agencies throughout Canada. A summary of this information may be listed as follows:

British Columbia

No recent research or development projects pertaining to the disinfection of wastes were reported by the Waste Management Branch of the B.C. Ministry of Environment, by the University of British Columbia, or by the laboratoires of the Ministry of Health.

Alberta

Effluents are not routinely monitored for bacteriological parameters. Research is confined to two areas. One project assesses the impact of disinfection residuals on biota downstream from a sewage outfall and is titled "Impact of the Chlorination of Municipal Sewage Effluents on Lotic Ecosystem". The other project, indirectly related to wastewater disinfection, evaluates the survival of helminth eggs, protozoan cysts and Enterobacteriaceae during waste treatment and is titled "Potential Health Problems Caused by the Disposal of Treated Sewage Products Containing Parasites".

Saskatchewan

No current research or development projects concerning wastewater disinfection were reported by Saskatchewan Environment.

Manitoba

Both total and fecal coliform tests are done routinely on effluents. There is a monitoring study on viruses in the Red River in the vicinity of Selkirk. Environment Canada (Bell et al, 1979) has completed a report examining the microbiology of the Red River.

Ontario

Effluent monitoring is normally completed for bacterial parameters. Considerable research has been done and is being done within the Ontario government and under contract to Ontario.

1) Within the Water Resources Branch, Ministry of Environment (MOE), studies have been done which:

   a) determine the decay of residual chlorine in the receiving stream, downstream of the outfall (Ontario MOE, 1978a & b);
   b) measure in situ toxicity;
   c) examine chlorinated organics in sewage (report available, others in preparation) (Ontario MOE, 1979).

2) Within the Pollution Control Branch (MOE), studies completed/ongoing include:

   a) optimization of the chlorination process (report under review);
   b) chlorination of waste stabilization pond effluents (report available in the form of technical notes);
   c) chlorine demand of raw sewage (internal document);
   d) The Applicability of UV Disinfection in Tertiary Effluent (report in print);
   e) The Applicability of UV Disinfection in Secondary Effluent (report in preparation). Results from studies (d) and (e) were summarized and presented at the Water Pollution Research Conference, Toronto, 1981;
   f) determination of the effect of wastewater disinfection on bacterial counts in raw water intakes (report in preparation);
   g) an investigation of the formation of chlorinated organics during the disinfection of secondary effluents (study ongoing);
   h) evaluation of the removability of coliforms in the stormwater effluents by sedimentation, chemically assisted sedimentation and chlorination;
   i) evaluation of the capital and operating costs, and the maintenance of a full-scale chlorination/dechlorination system (ongoing).

3) Within the Canada-Ontario Great Lakes Water Quality Agreement studies include:

   a) examination of stormwater runoff for bacterial content;
   b) evaluation of wastewater disinfection alternatives (report available);
   c) examination of SO_2 and ponding for dechlorination.

4) Under the Provincial Lottery, environmental health projects under way or completed include:

a) tracing the sources of bacterial counts in urban drainage systems, and their removability by street sweeping, sedimentation, chemically-assisted sedimentation, and chlorination. (ongoing);
b) examining ozonation of drinking water (ongoing);
c) studying virus dispension in sewage and the environment (report available, University of Ottawa);
d) examining bacterial levels in the receiver with and without disinfection (ongoing);
e) applying UV disinfection in selected sewage treatment plants and assessing the significance of photo-reactivation. (ongoing);
g) epidemiological investigations of bathing beaches and recreational waters.

5) Miscellaneous investigations include:

a) applicability of a chlorine monitoring probe in a Windsor Primary Sewage Treatment Plant (internal report available);
b) a full scale demonstration of UV disinfection technology in an Ontario Secondary Sewage Treatment Plant. (ongoing).

Québec

No reports have been received from this province.

New Brunswick

Effluent monitoring for bacteria is not normally done beyond that associated with the shellfish program. No research activities concerning wastewater disinfection have been reported at the present time.

Nova Scotia

Effluents are normally monitored for bacterial parameters. Currently research is being conducted on storm water quality and quantity at the Technical University of Nova Scotia.

Prince Edward Island

No research activities concerning wastewater disinfection have been reported at the present time.

Newfoundland

Effluent bacterial monitoring is carried out on a regular basis. No research activities concerning wastewater disinfection have been reported and none is planned for the immediate future.

Northwest Territories

Effluents, under normal circumstances, are monitored for total and fecal coliforms. Two projects, respectively titled, "Environmental Effects of Domestic Waste Discharges to Marine Arctic Waters" (Associated Engineering Services Ltd., 1980) and "Potential Impact of Wastewater from Communities on the Laird, Peel and MacKenzie Rivers "(Associated Engineering Services Ltd., 1978) examine the consequences of wastewater discharges to northern waters. An ongoing project, "Examination of Sewage Outfall Design and Wastewater Mixing Criteria from Community Discharges along the MacKenzie River and Slave River in the Northwest Territories" is being conducted by Drs. D.W. Smith and R. Gerard, University of Alberta.

Department of National Health and Welfare

No specific studies are underway at the present time concerning wastewater disinfection. Considerable effort is going into studies related to trihalomethane formation and potable water disinfection as well as the reaction products of alternate disinfectants.

Environment Canada

Aside from the work which has been reported under the Canada/Ontario research agreements, much of the present effort is directed towards definition of environmental contaminants in sewage effluents. Some biological testing is also under way on pre- and post- chlorinated effluents.

A joint project to be carried out under the research program of the Canada - U.S. Great Lakes Water Quality Agreement will collect epidemiological data in the Great Lakes.

6.2 Research Needs

Additional research is required in the assessment of the public health implications of municipal wastewater discharges and the environmental consequences of disinfection processes. Some of these needs include:

1) Disinfection Alternatives

Evaluation of disinfection alternatives, particularly ozonation and ultraviolet irradiation, should be undertaken to address: (1) the level of application needed for effective removal of pathogens from municipal wastewater effluents; (2) the byproducts formed duirng the disinfection process and their concentrations; and (3) the impact of these byproducts and disinfectant residuals on human health and aquatic biota.

2) Survival and Regrowth of Pathogens in Aquatic Environments after Effluent Disinfection

The microbial population and quality of a water course reflects the interplay of numerous environmental parameters with the water, as it flows from its fresh water sources towards an estuarine condition of varying salinity and finally into the ocean. Although many of the organisms found in a receiving water have no sanitary significance, species of pathogenic protozoa, bacteria, and virus, including indicator organisms, are of considerable importance to public health.

Information relative to the regrowth and survival of pathogenic and indicator organisms as affected by the numerous environmental factors taken collectively, should be clarified and evaluated.

3) Wastewater Chlorination and Formation of Toxic Chemicals

Chlorine is currently the major disinfectant used in Canada. The formation of a multitude of organohalogen substances has been demonstrated during disinfection of both potable water and wastewater. The impact of these chlorinated organics on human health and aquatic biota should be researched to determine their environmental persistence, bioaccumulative potential and mutagenic and carcinogenic properties.

4) Indicator Organisms

The present state of knowledge regarding the relationship of indicator organism concentrations to: (1) disease outbreak; (2) pathogenic organisms; and (3)

infections, is inadequate. Controlled epidemiological-microbiological studies should be undertaken to develop scientifically-sound, health-related microbiological water quality and effluent criteria, and better indicators.

5) Resistance Transferable R-Factors in Coliforms and Fecal Coliforms in Water

As a result of the widespread use of antibiotics, R-factors which transfer antibiotic resistance among the Enterobacteriacae have become common in the intestinal tract of man and domestic animals. Many of these bacteria would be expected to enter sewage and ultimately occur in waste and river waters. This has been shown to be true by the recent work of Bell et al (1980) in their study of the microbiology of the Red River in Manitoba. Since these organisms, containing multiple antibiotic resistance, have possible health hazards, it would seem desirable to: (1) know how extensively this phenomenon is occurring in our waters; and (2) how the reduction of these R(+) bacteria in the water environment could be accomplished.

6) Effectiveness of Viral Kill Using Chlorine

It has been demonstrated that most viruses are much more resistant to chlorine than the indicator bacterial organisms normally used to measure the effectiveness of the chlorination process. It is possible that significant densities of viruses are being discharged to the environment from plants using classical treatment techniques.

Additional work is required to more fully define the effect of chlorine on viruses under field conditions and, eventually, to optimize the reduction of viral densities in wastewater effluent utilizing chlorine and alternate disinfectants.

7) Chlorine Residuals

Development of field and laboratory chlorine residual measurement methods and equipment that effectively function at residual levels of environmental concern (i.e. 0.01 mg/L and above), appears to be of importance.

8) Methods of Detection of Viruses and Parasites

It is evident from limited research information that removal of viruses and parasites by existing wastewater treatment techniques may be inadequate for health protection. In order to fully evaluate the extent of this threat it is necessary to have

reliable, sensititve and reproducible field and laboratory techniques for the detection of viruses and parasites in waste-, and drinking waters.

9) Disinfection of Primary Effluents

The disinfection of primary effluents is an area of wastewater treatment that has not been extensively researched. Further research should be initiated to determine: the level of pathogen reduction achievable; the required disinfectant dosages; the required disinfectant residuals; the nature and concentration of byproducts formed in the process; the potential for reconcentration of byproducts formed in the process; the potential for regrowth/reactivation of pathogens and indicator organisms; and the potential for detoxifying the disinfected effluent prior to discharge.

10) The Application of Storage Ponds

The application of storage ponds for dechlorination of chlorinated wastewater discharge should be evaluated to determine design and operating parameters.

11) The Survival of Indicator and Pathogenic Organisms in Sewage Lagoons

Waste stabilization ponds are one of the most commonly used methods of treating domestic wastewater in North America. As the microbiological quality of effluents from waste stabilization ponds can be of public health significance, it is desirable to know the efficiency of pond systems in removing pathogenic organisms and the physical, chemical and biological factors affecting removal rates.

Evaluation of the effects of nutrients, plant growth, pH, dissolved oxygen, microbial antagonism and hydraulic regimes on bacterial die-off in lagoon systems and determination of relationships between pathogen survivals and indicator organism survivals in lagoon systems should be done.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Rationalization of the need for disinfection of municipal wastewater was developed by reviewing available information in three pertinent areas:

(1) existing practices
(2) public health implications
(3) environmental implications

The conclusions of the Working Group have been included in the body of the report at the end of each section dealing with these respective issues. An overview of these conclusions may be summarized as follows:

7.1.1 Existing Practices

(1) Microbiological contamination of surface waters originates from a variety of sources including municipal wastewater treatment plants, stormwater runoff, combined sewer overflows and treatment plant bypasses, industrial effluents and other related non-point source discharges. The impact of any one discharge on a receiver, and its control, cannot be viewed in isolation but rather must be considered in conjunction with all other discharges that influence the microbiological characteristics of a receiver.

(2) There are several sources of residual chlorine loadings to the environment including effluents from municipal sewage treatment plants, industrial discharges and cooling waters from power plants. The elimination or reduction in the use of chlorine at municipal sewage treatment plants will, to some degree, reduce the potential for chlorine-induced toxicity in receiving waters but, because of these other sources, will not necessarily eliminate the problem. In addition, it is recognized that the lethality of municipal effluents is not solely a function of residual chlorine concentrations. Other constituents in municipal effluents, including ammonia, sulphides, heavy metals, oil and grease, trace organics, and surfactants, affect the toxicity of an effluent. The level of treatment provided to a municipal effluent is an important factor in reducing the toxicity of municipal wastewaters.

(3) Disinfection of raw sewage, sewage treatment plant bypasses and combined sewage overflows is for the most part a practice that has been found to be ineffective.

Treatment of municipal wastewaters enhances the effectiveness of the effluent disinfection process. As a minimum, primary clarification of raw sewage should be required prior to the application of chlorine for disinfection purposes. However, if effluent bacterial target levels cannot be achieved using less than 25 mg/L chlorine dosage or as an alternative an end-of-contact total residual chlorine (TRC) of less than 2.5 mg/L, then a higher level of pretreatment and/or improvements to the disinfection process will be necessary. Bacterial target levels of 2 500 total coliform/100 mL and 200 fecal coliforms/100 mL have been cited as a minimum requirement for satisfactorily disinfected effluents.

(4) The potential for improving the design, operation and control of wastewater chlorination processes at many sewage treatment plants is a valid concern of both public health and environmental agencies. The upgrading of disinfection processes offers the capability of increased control over levels of microbiological contaminants and residual chlorine concentrations in municipal discharges to the environment.

(5) Lagoon systems can be designed and operated with detention times that obviate the need for effluent disinfection. However, short detention lagoon systems (i.e., lagoon systems with hydraulic residence times of 30 days or less) will normally require chlorination of effluents prior to discharge.

(6) Some promising disinfection alternatives to chlorination processes include ultraviolet irradiation and ozonation. In addition, other disinfecting compounds and processes are being researched. Although these alternatives may prove more costly than chlorine, the production of an effluent that does not result in disinfection-induced toxicity in the receiving environment is a benefit that justifies further development and application of alternative disinfection technologies.

7.1.2 Public Health Protection and the Application of Wastewater Disinfection

(1) Municipal wastewaters contain pathogenic microorganisms that have been identified as etiologic agents of disease and infection to man and animals.

(2) Coliforms have traditionally been employed as indicators of fecal contamination in surface waters. However, various problems are associated with the use of coliforms for this purpose, namely:

(a) some strains of the coliform group may originate from soils, vegetation and from industrial discharges;

(b) survival times for organisms of the coliform group in the receiving environment are variable and are dependent upon site-specific factors;

(c) relationships between indicator bacteria and pathogenic bacteria or viruses are inconsistent and unpredictable in sewage, treated municipal effluents, chlorinated wastewaters and surface waters.

There is little doubt that use of indicator bacteria to predict fecal contamination of surface waters (and ultimately to assess the threat posed to human health as a result of receiving water use) will continue until other methods of pathogen detection are developed and proven. However, reliance on this method as a sole means of determining the utility and effectiveness of pathogen control at sewage treatment plants and the health protection being afforded to users of receiving waters is questionable.

(3) Recognized pathways of disease transmission via the water route include drinking water supplies, recreational waters, shellfish waters and agricultural/irrigation waters. These potential routes may be identified on a site-specific basis and examined to determine the possibility of public contact with infectious pathogens as a result of municipal wastewater disposal operations. Natural environmental defences, as well as modern design and technology, may be employed to break cycles of infection and prevent disease transmission; wastewater disinfection is one of the man-made defences that may be used. The employment of any single barrier or combination of barriers against disease transmission is dependent upon site characteristics and receiving water uses.

(4) Adequately treated and delivered drinking water should not contain any pathogenic microorganisms. A realistic expectation is that even under epidemic conditions of illness in the population whose sewage may contaminate the raw water source, the combination of wastewater treatment, natural purification in receiving waters and water treatment will be such that outbreaks of disease are unlikely to occur.

(5) Primary contact recreation in surface waters carries with it the inherent characteristic of increased risk of infections and irritations of the skin, ears, nose and upper respiratory tract. There is a lack of direct causal evidence linking discharges to outbreaks of disease except under conditions of heavy contamination with human wastes or during epidemic conditions.

(6) Typhoid fever, gastroenteritis of unknown etiology and infectious hepatitis have accounted for over 90% of the shellfish-related disease outbreaks since 1900. The source of the causative organism is clearly related to fecal discharges; however, existing indicator bacteria representative of human fecal wastes will not predict the potential risks of these less frequent waterborne diseases.

(7) Available evidence suggests that land disposal of wastewater is not a major mode of disease transmission in Canada. It is anticipated that the use of this disposal option will increase in the future and thus the exposure of the general population to lands or crops irrigated with wastewaters will increase. Therefore, the human health implications of land disposal of wastewater need to be addressed in greater detail.

(8) Existing research and epidemiological data do not provide conclusive evidence that low level exposure to halocarbons in water represents a significant health hazard. However, any practice that significantly increases the organic chemical burden on a water supply represents a potential risk to human health and as such should be controlled or reduced, pending further risk assessment.

7.1.3 Wastewater Disinfection and Environmental Impact

(1) The absence of reports on massive fish kills in Canada as a result of residual chlorine discharges cannot be taken to mean that fish kills do not occur or that habitat has not been alienated by residual chlorine discharges. Laboratory and controlled field studies have demonstrated numerous adverse effects which probably occur within the environment for which field documentation is not available.

(2) Residual chlorine concentrations as low as 0.02 mg/L are acutely toxic to some freshwater and marine organisms. Chronic toxicity effects have been observed at residual chlorine levels in the order of 0.001 mg/L. Research information indicates that the biological effects from exposure to chlorinated effluents vary with the aquatic species, water quality characteristics (freshwater or marine) and the characteristics of the discharged effluent.

(3) Avoidance of residual chlorine discharges by fish in a freshwater or marine receiver is species specific and cannot be relegated to a precise code of behaviour. Where avoidance occurs, it may:

(a) result in a reduction in the amount of available habitat;

(b) result in displacement to less favourable habitats with subsequent impact on productivity; or

(c) interfere with the migratory success of fish.

(4) Limited research into the effects of chlorinated organic compounds on aquatic organisms (freshwater and marine) has been conducted. Aquatic toxicity work has been undertaken for a variety of chlorinated organic compounds and mixtures of compounds and several aquatic species. Conclusions cannot be made on the overall impact of chlorinated organics related to wastewater disinfection practices on aquatic organisms until more research has been completed.

(5) Little attention has been focused on the impact of chlorinated organic compounds on land in wastewater disposal/reuse operations. Uptake of organic contaminants by soils, vegetation and/or direct uptake by animals, as well as leaching of organics to groundwater, are areas of research that should be expanded.

7.2 Recommendations

Municipal effluents are an identifiable source of microbiological contamination which can represent a direct or indirect threat to human health. The natural environment does afford some opportunity to attenuate this threat. Disinfection processes used to reduce microbiological contamination may themselves create new hazards to human health or cause significant adverse response in the aquatic environment. It is difficult for universal policies to effectively deal with this apparent conflict and for this reason site-specific resolution is recommended.

Some general recommendations on site-specific assessment include:

(1) The discharge of microbiologically contaminated municipal effluents to surface waters should be assessed on the basis of existing or proposed usage of receiving waters, the associated risk to human health and the existence of other sources of contamination.

(2) When a potential health hazard has been identified, the selection of wastewater treatment processes, the operational control of treatment facilities and the location of effluent outfalls should be such as to protect both human health and the environment.

(3) When the need for wastewater disinfection has been verified at a site, the potential effects of the disinfectant residuals and byproducts on the aquatic ecosystem must be defined, and where necessary, appropriate remedial steps implemented.

(4) When disinfection is required, it should be practised in a manner that ensures effective control of the identified human health hazard.

Section 5 of this report details a strategy that may be employed in achieving these general recommendations.

Specific recommendations of the Working Group include:

(5) Information on the design, operation and control of wastewater chlorination/dechlorination systems should be collected and disseminated for the purpose of upgrading existing wastewater disinfection criteria and practices.

(6) Based on limited research in the area, it has been demonstrated that effluent with total coliform counts of 2 500/100 mL and fecal coliform levels of 200/100 mL can be consistently produced using current chlorination technology with nominal dosages and proper operating conditions. The Working Group considers the above levels reasonable objectives for effective disinfection. Site details and specific water uses, however, will dictate effluent disinfection requirements.

(7) Target bacteriological limits in a disinfected effluent should be correlated with applied disinfectant dosages and/or residuals for operational control purposes. If target levels cannot be achieved with a chlorine dosage of 25 mg/L or an end-of-contact total residual chlorine of 2.5 mg/L, then upgrading of the pretreatment processes or the disinfection system should be undertaken.

(8) Target bacteriological limits in wastewater effluents should be crosschecked occasionally with measurements of pathogenic bacteria and viruses to reaffirm the effectiveness of disinfection processes in destroying the organisms of concern.

(9) Receiving waters should be monitored regularly to determine compliance with bacteriological water quality objectives. Occasionally, analysis for pathogenic bacteria and viruses should be included in the monitoring program to establish historical relationships and to identify trends and potential problems.

(10) Controlled epidemiological-microbiological investigations of recreational and shellfish-growing waters should be undertaken to develop health effects criteria.

(11) Research into the risk to human health of the ingestion of quantities of organic chemicals found in drinking water supplies should continue with the development of refined data collection systems and analytical techniques and sound epidemiological study designs.

(12) A national reporting system for waterborne disease outbreaks should be further developed to provide a reliable Canadian reference.

(13) Resource management and environmental agencies should initiate or continue to document case histories and site evaluations which demonstrate the adverse impact of disinfected effluents on aquatic organisms.

(14) Research related to the human and environmental consequences of wastewater disinfection practices must be initiated and/or suported by federal and provincial agencies in order to establish a scientifically-sound uniform policy. The areas of research that have been identified by the Working Group are: the research and development of scientifically-sound microbiological standards for human health protection; the survival and regrowth potential of pathogens in the environment; the formation of toxic chemicals in wastewater disinfection processes; disinfection alternatives to wastewater chlorination; resistance transferable R-factors in pathogens; the survival of indicator and pathogenic micro-organisms in sewage lagoons; the effectiveness of chlorination processes in virus removal; methods of detection of viruses and parasites; the development of reliable low level chlorine residue measurement methodology and equipment; the application of storage ponds for the dechlorination of wastewater effluents; and the optimization of the disinfection of primary effluents.

(15) A standing body comprised of federal and provincial representatives from environmental and public health agencies should be organized to identify, priorize, coordinate and monitor the research needs associated with wastewater disinfection, as well as disseminate research information for practical application in this country. Central agencies (e.g. Health and Welfare Canada and Environment Canada) should assume responsibility for managing this program and use the proposed federal/provincial group in a technical advisory role.

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